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Renewable energy production in Spain: A review

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ABSTRACT

This paper reviews the production and consumption of traditional and renewable energy in Spain over the past two decades. It also presents an overview on the development of renewable energy, such as solar (photovoltaic and photothermal), wind, biomass, hydropower, marine and geothermal energies in Spain. A brief overview of the legislation regulating renewable energy in Spain is offered. It was shown that the installed renewable energy of 32,472 MW represented 11.6% of the country's primary energy consumption. Furthermore, the installed renewable energy average of electric power in Spain was 0.7 kW per capita and 59 kW/km^2. Wind energy continues to experience a good growth rate, and does not seem to be affected by regulations, which has made it the most sustainable renewable energy in Spain. Finally, an analysis of energy production and consumption, renewable and non-renewable energy by province is made. The data indicates that highly populated and industrialised provinces made more efficient use of their energy from an electrical consumption viewpoint. This uneven growth was not motivated solely by the existence or lack of renewable energy resources but by the autonomous community or province in their socio-economic context.

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Contents

1. Introduction

The growing need for energy in western societies and, above all, in developing ones, has posed a major challenge to the

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Table 1
National overall targets for the share of energy obtained from renewable sources, expressed in terms of the gross final consumption of energy in 2020.

Countries	Share of energy from renewable sources in gross final consumption of energy, 2005%	Target for share of energy from renewable sources in gross final consumption of energy, 2020%
Belgium	2.2	13
Bulgaria	9.4	16
Czech Republic	6.1	13
Denmark	17	30
Germany	5.8	18
Estonia	18	25
Ireland	3.1	16
Greece	6.9	18
Spain	8.7	20
France	10.3	23
Italy	5.2	17
Cyprus	2.9	13
Latvia	32.6	40
Lithuania	15	23
Luxembourg	0.9	11
Hungary	4.3	13
Malta	0	10
Netherlands	2.4	14
Austria	23.3	34
Poland	7.2	15
Portugal	20.5	31
Romania	17.8	24
Slovenia	16	25
Slovak Republic	6.7	14
Finland	28.5	38
Sweden	39.8	49
United Kingdom	1.3	15

establishment of new energy policies [1]. Traditional approaches have increased generation with increasing needs [2], but recent years have seen a greater emphasis on energy-saving strategies [3] and sustainability [4,5]. The industrial sector, which uses more energy than any other end-use sectors, currently consumes approximately 37% of the world's total delivered energy [6].

The success of the evolution of human civilisation has been linked to the orderly and sustainable growth of resources and energy utilisation [7]. Forecasts and trend studies have indicated that civilisation is now facing a major energy challenge, and it will not be easy to achieve the objectives set for the coming years, especially with the pressure of large growth in emerging countries such as India [8–10], China [11], and Brazil [12,13]. This pressure has stemmed from high levels of underdevelopment, especially in rural areas [14–16], and underdeveloped countries aspire to catch up to the developed countries and engage in the greater consumption of energy that this achievement implies [17]. It has become clear that the measures and policies needed to implement solutions on the global level should be developed using the factors mentioned above, including research [18], the contribution of renewable energy sources [19–21], and the utilisation of urban, agricultural [22,23], and industrial waste [24] as new sources of energy [25].

Nearly 40% of the European Union's final energy demand comes from domestic public and corporate consumption [26]. According to Europe's Energy Efficiency Plan, the biggest energy savings potential in the EU lies in the built environment [27]. The EU is one of the major drivers of efficiency measures [28], energy savings [29,30], and the development of renewable energies [31]. European governments have agreed to increase the share of renewable energy in final energy consumption to 20% by 2020 [32]. The EU's energy policies have been active since 1986 due to the initiatives of the European Council. With Directive 2009/28/EC, the European Parliament and Council have laid the ground for a policy framework on renewable energy sources (RES) in the European Union until 2020 [33]. Programs, such as ALTENER, and reference documents, such as the White Papers [34,35] and Green Papers [36], have allowed for the advancement of sustainable energy growth policies that aid in the fight against global warming and climate change. The EU Green Paper on energy efficiency has called for action to decrease energy use and thus achieve increased competitiveness, fulfil environmental targets, and increase the security of the region's energy supply [36]. The promotion and stimulus of the renewable energy sector (RES) has been one of the clearest examples in this regard. Under the Kyoto protocol, the European Union (EU) has agreed to reduce greenhouse gas (GHG) emissions by 8% between 2008 and 2012 relative to 1990 levels. For example, tradable green certificate (TGCs) schemes have been developed and tested in several European countries to foster the market-driven penetration of renewable energies. These certificates guarantee that a specific volume of electricity is generated from renewable energy sources (RES) [37]. Table 1 shows the target renewable electricity production quotas in relation to the total production for the 2020 horizon [38]. The data show that the specified renewable energy production goals were achieved until 2020, but the majority of countries in the EU-27 have distanced themselves from their objectives since 2011. As a result, only Estonia, Austria and Sweden will be able to fulfil their national goals for 2020.

Spain is a clear example of a negative trend in the fulfilment of the 2020 renewable energy objectives. Recent reports have shown that the best-case scenario projection is within the range of 12.6–17.1%, far from the forecasted goal of 20%. The projection also represents a clear breach of the objectives in the National Action Plan for Renewable Energy [39], which gives a goal of 22.7%, and the plan drawn up by the Spanish government through the Plan for Renewable Energies (Spanish initials PER), which forecasts 20.8% over 2011–2020.

Energy dependence indicator shows the extent to which an economy relies upon imports in order to meet its energy needs; it is calculated as net imports (total imports minus total exports) divided by the sum of gross inland energy consumption [40]. Energy dependence may be negative in the case of net exporter countries while positive values over 100% indicate the accumulation of stocks during the reference year.

These failures have meant that Spain's energy dependence (see Fig. 1) will continue to be a key factor in the country's economic recovery and emergence from crisis [41]. Spain's energy dependence (76.44%) is well above the average for the EU-27 (53.84%). Only Denmark has a negative balance because wind power has been the main element of Danish renewable energy policy [42].

Spain's dependence has only increased in recent decades, although the impetus of the renewable energy sector has reversed this trend since 2007 (see Fig. 2). The Spanish government approved the Renewable Energy Plan in 2005, assuming a goal of 12.1% RES-E share by 2010 and an overall renewable share of 22.7%, or 37.5% when considering only the electricity sector [43].

Spain consumed 14.9 Mtoe of renewable energy in 2011, which represented 11.6% of the country's primary energy consumption. Biomass, wind and hydropower are the main sources of renewable energy. In terms of power generation, the gross renewable energy production amounted to 86,600 GW h, or 29.7% of the country's total. This distribution implies that renewables are the main source of electrical energy for the country, surpassing natural gas (28.9%) and nuclear power (19.7%). The distribution within the renewable energy sector by type has indicated an 84% contribution by wind and hydropower (49% and 35%, respectively), which is an

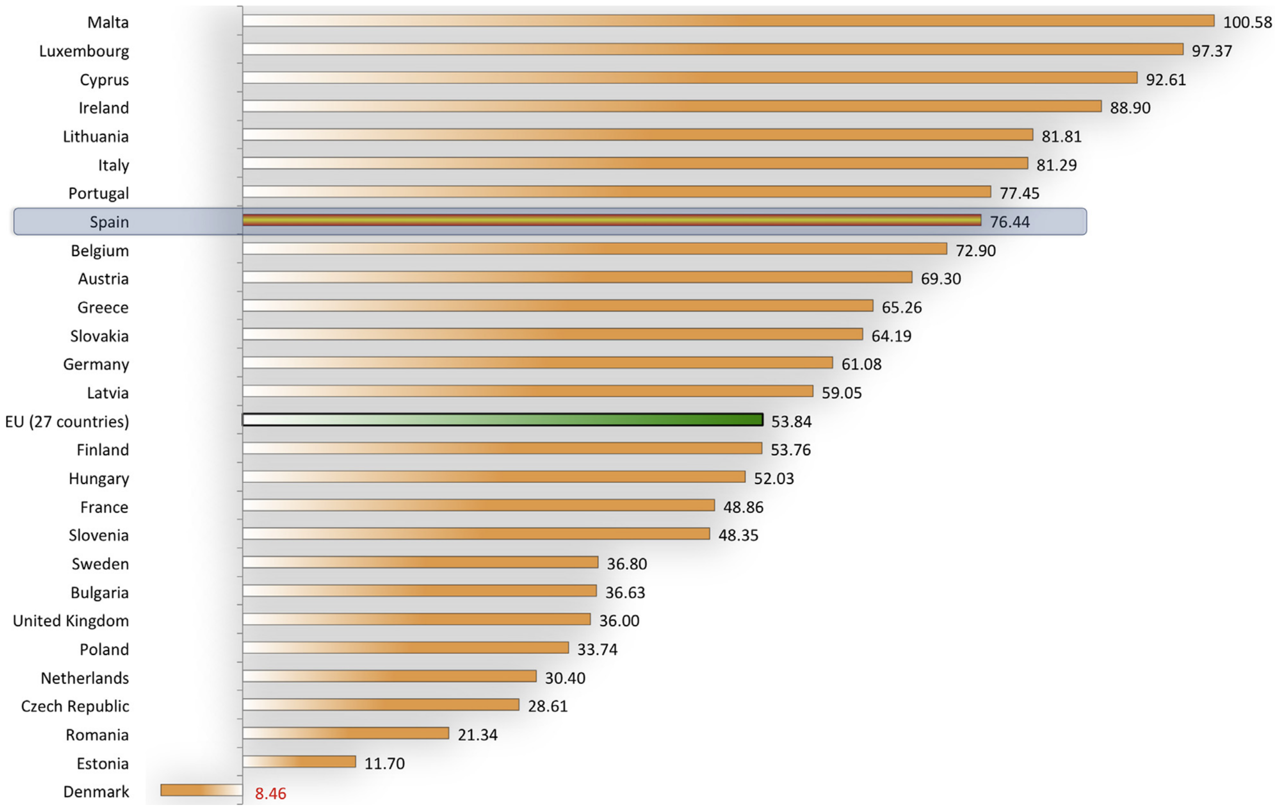

Fig. 1. Energy dependence of the EU-27 countries in 2011 [40].

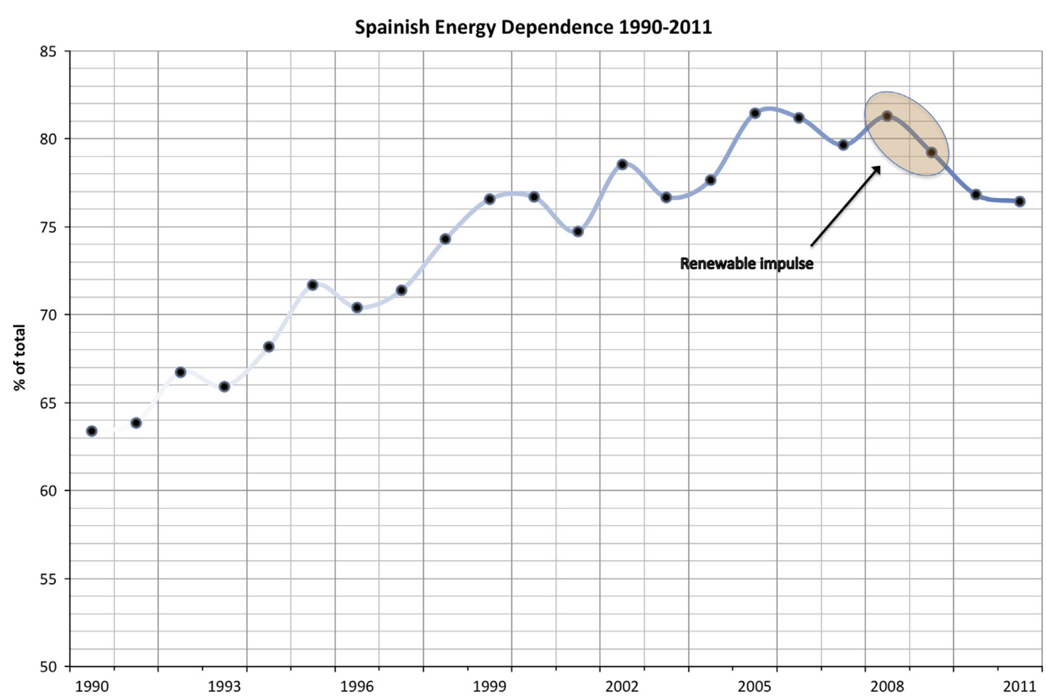

Fig. 2. Spanish energy dependence over the period 1990–2011 [40].

11% decrease from 2010 due to a year of reduced hydraulic and wind resource availability. For example, on April 16, 2012, at 3:48 h, 60.46% of the mainland demand (21,098 MW) was covered by wind power (12,757 MW), surpassing the previous high of 59.63% registered on November 6, 2011, at 2:00 h [44].

2. Electric power consumption in Spain

Energy consumption in Spain was growing from the 1970s until 2008. Since then, the trend has reversed. Fig. 3 shows the annual series for the period 1990–2011. Spain has one of the lowest levels

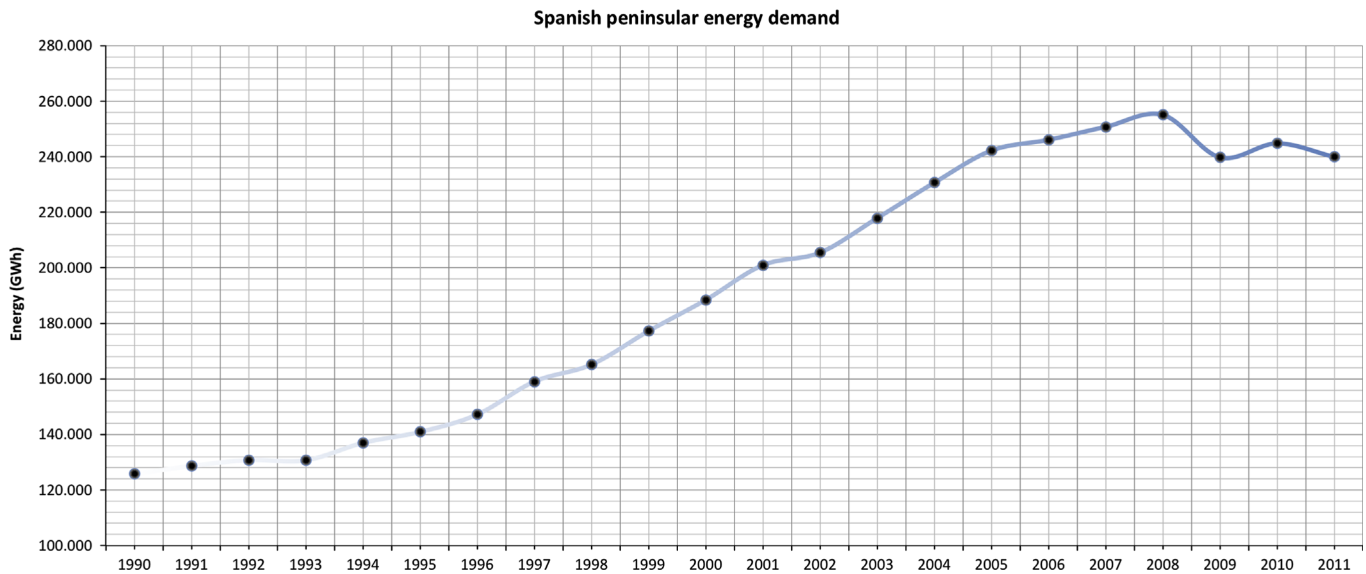

Fig. 3. Energy consumption in the Iberian Peninsula (excludes Canary Islands, Balearic Islands, Ceuta, and Melilla) for the period 1990–2011. Source: Eurostat.

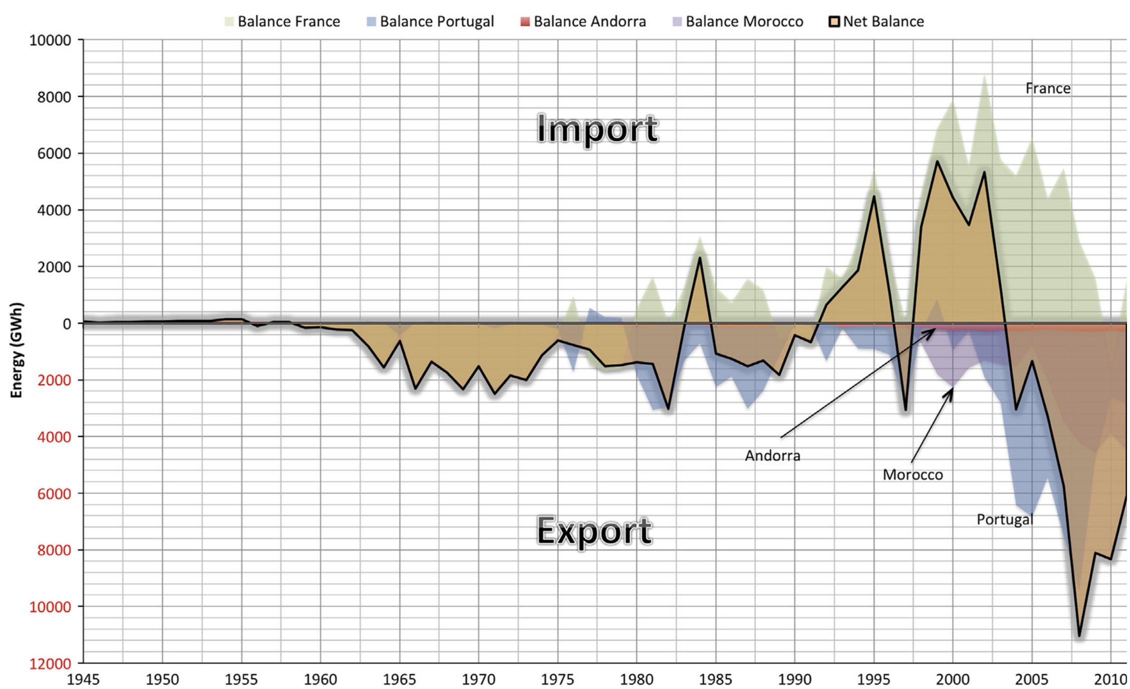

Fig. 4. Spanish energy balance in international electrical energy exchanges for the period 1945–2011. Source: Unesa [51].

of per capita energy consumption of fossil and non-fossil fuels among the EU-15 countries [45].

Spain's final electric power demand (including the island systems, Ceuta and Melilla) in 2011 was 252,848 GW h, which represented a decrease of 3% from the previous year [46]. The power capacity in the Spanish peninsula exceeded 100 GW, while minimum and peak power demands reached only 17.8 and 44.1 GW h/h, respectively [47,48]. This effect has been attributed to lower economic activity after the recovery of certain industrial sectors in the previous year and the differences in seasonal use and temperatures between the two years (Spain experienced increasingly higher electrical consumption during the summer months due to the expanding use of cooling systems) [26]. The average consumption of a Spanish home was 10,521 kW h, of which 47% corresponded to heating and approximately 19% to sanitary hot water [49]. After a sharp decline in the previous year, the major increase in energy production in coal-fired power stations (+ 70.7%) increased to 15.4% of the national total. The spread of this plant type of plant has been essential to the nation's back-up power supply [50].

Despite Spain's energy dependence, it ended the year 2011 with an exporter balance of 6090 GW h in terms of international energy exchanges. The historical evolution of this variable, as represented in Fig. 4, indicates that the Spanish electricity sector has had negative balances, or exporter status, from the 1950s almost until the 1990s. The sector then entered a period of positive balances, or importer status, from the early 1990s until 2003, when it reverted to the exporter status it has maintained until today.

In 2011, Spain obtained a positive balance (importer) of 1524 GW h with France, while Portugal and Morocco created negative balances (exporter) of 2814 GW h and 4494 GW h,

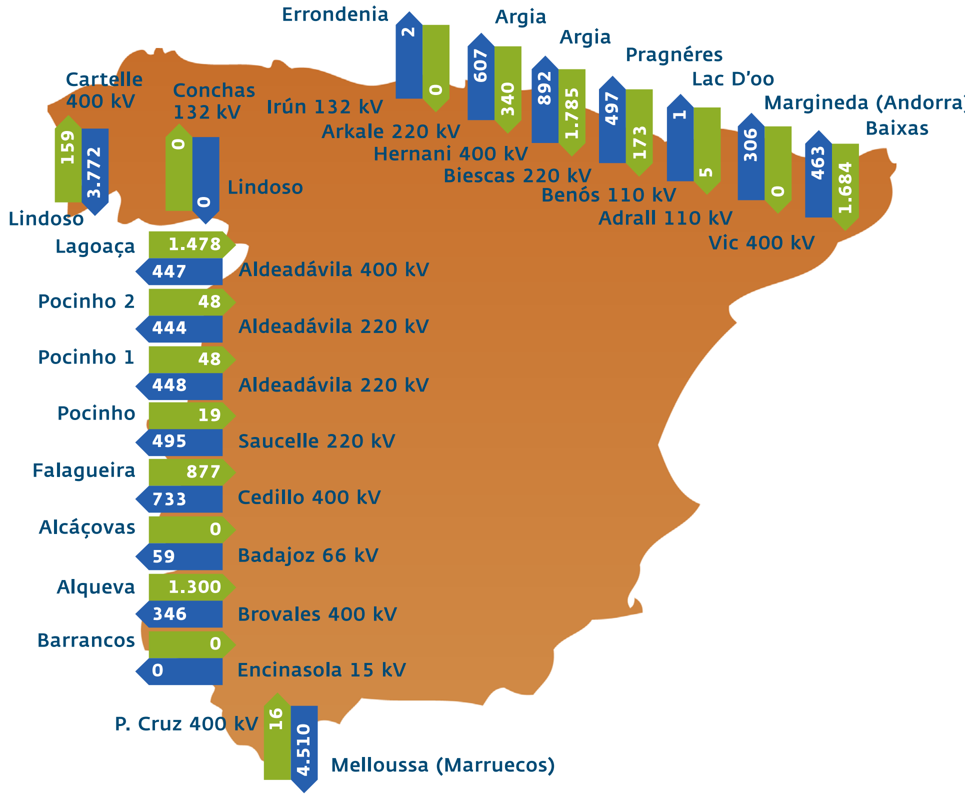

Fig. 5. Electrical energy exchanges for the year 2011. Source: REE [47]. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)

respectively. Spain has traditionally been mainly an importer of French power in terms of net energy, as shown in Fig. 4 for the last 10 years, with the sole exception of the balance recorded in 2010. However, connections with Portugal and Morocco have been developed with Spain as a general exporter in terms of net balances. In Portugal, distributed generation (namely through wind parks) is paid using feed-in tariffs, while Spain can choose between receiving a regulated feed-in tariff or the market price and a participation prize [52].

Fig. 5 shows the physical interconnections (kV) that exist among Spain and France, Portugal, Andorra, and Morocco, and the exporter (blue)/importer (green) balance sheet (GW h) with each country for the year 2011. The export of electrical power to Morocco via the 400-kV Melloussa line stands out in particular among these interconnections.

3. Renewable energy production in Spain

The importance of the renewable energy sector to the Spanish economy has been growing, and its contribution will increase in the next few years. In constant terms based on 2010 values, the direct contribution of the renewable energy sector to Spain's gross domestic product (GDP) has shown positive development, accumulating a growth of approximately 56.7% over the period 2005–2009. Considering the published International Monetary Fund forecasts for the Spain's growth in GDP until 2015, and assuming an annual growth of 2.5% between 2016 and 2020, the direct contribution of the country's renewable energy sector will represent 0.88% of its GDP in 2015 and 1.03% in 2020.

The potential for Spanish renewable energy is broad, and far superior to its domestic energy demand and existing fossil-based energy resources. It could even be said that renewable energies are Spain's main energy asset.

Among these energies, the potential for solar energy is the highest. Expressed in terms of installable electrical power, Spain has the potential for several terawatts (TW) of solar energy. Wind power takes second place, with a potential estimated at approximately 340 W. The country's hydroelectric potential, estimated at approximately 33 GW, is also very high, but the greater part of this potential has already been developed. The remaining technologies have a potential near 50 GW, the potential for wave and geothermal energy approximately 20 GW each [53].

3.1. Solar energy

Spain has hours of sunshine than almost any other country in Europe, along with the countries in the Mediterranean arc, and therefore offers optimal conditions for solar energy [49]. The average values of sunshine (in hours per year) vary from 1600 h on the northern zone to as much as 3100 h on the southeastern zone [54]. The average solar radiation varies between 1.5 kW h m^{-2} in winter and 7 kW h m^{-2} in summer in the country's southern areas [55–57]. The national average is 1600 kW h m^{-2}. Fig. 6 shows a detailed map of the annual accumulated horizontal solar radiation level for the entire country.

3.1.1. Photovoltaic energy

In 2006, Spain ranked fourth worldwide (after Germany, Japan, and the USA) in installed photovoltaics (PV), with 97 MW [58]. In 2007, 400 MW of electrical installed power was distributed among 14,567 existing facilities. In 2008 and 2009, Spain climbed to second place (after Germany) in installed power [59]. The total power accumulated in 2012 reached 4525 MW.

Fig. 7 shows the development of the country's annual installed PV power and the total amount connected to a network until 2012,

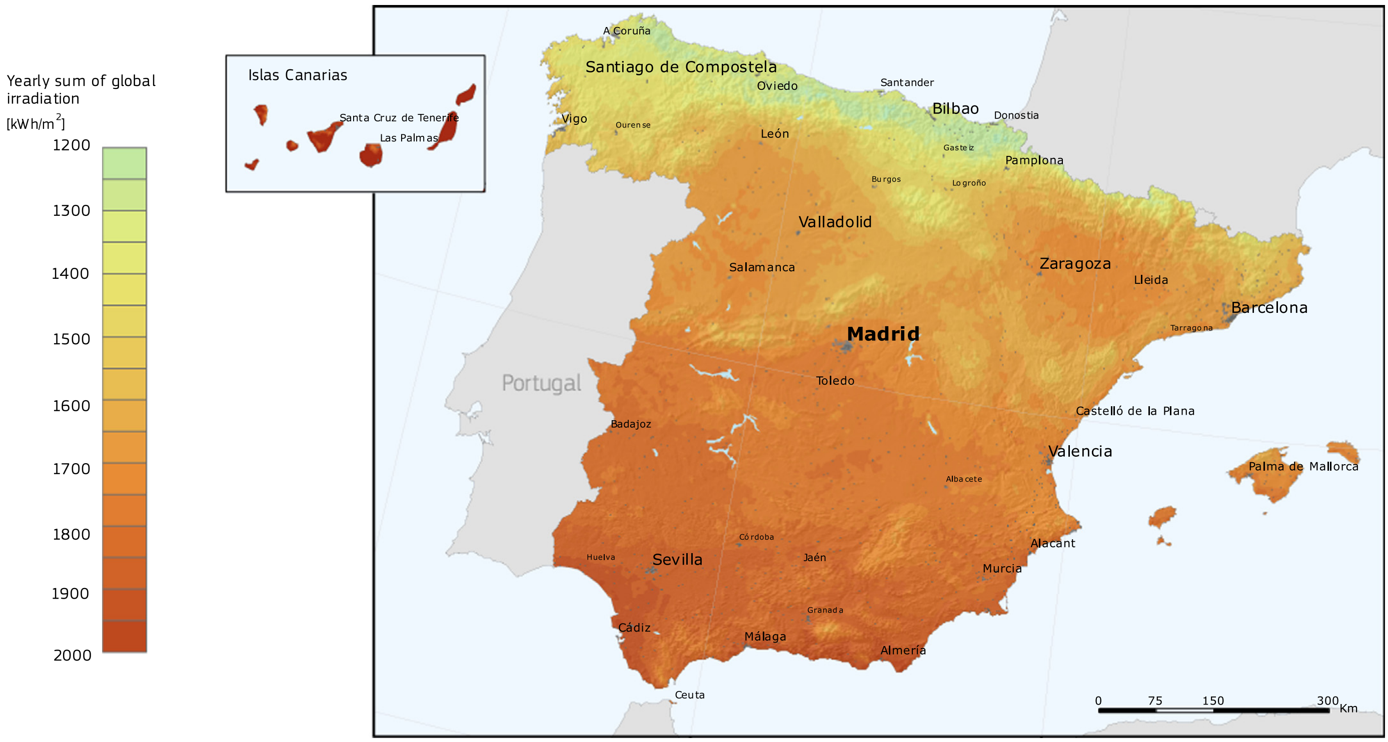

Fig. 6. Horizontal global irradiation in Spain. Source: PVGIS© European Union.

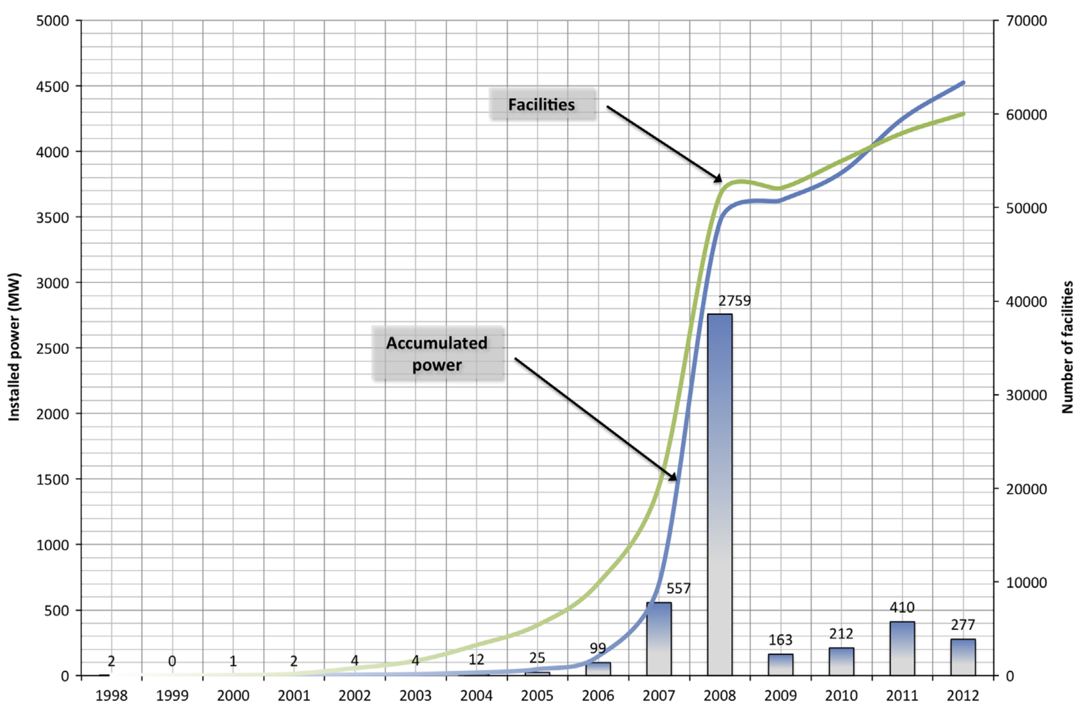

Fig. 7. Development of installed photovoltaic power and number of facilities over the period 1998–2012.

along with the number of facilities connected to the network. The total number of installations was 60,012 by the end of 2012.

The years 2007 and, in particular, 2008 saw a significant increase in installed power, from a few tens of MW in previous years to almost 3500 MW in the year 2008. This increase was facilitated by a new energy regulation, RD 661/2007 (Royal Decree RD 661/2007 of May 25, regulating electricity production in the special regime), which established new energy tariffs starting on June 1, 2007, with a 25-year feed-in-tariff system [60]. However, the country experienced a decrease in newly installed power in 2009 due to the enactment of new laws and ordinances that restricted, and then removed, previously established incentives for the sale of electricity generated with PV systems. Yet the solar PV industry was still the first to reach the goals set forth in the Plan of Renewable Energy 2005–2010, demonstrating its capacity for adaptation and cost reduction in achieving these objectives.

The current situation has been worrying for the sector, and the association that encompasses the producers and investors of PV, ANPIER, has repeatedly stated its concern. Royal Decree 1565/2010 has limited compensation to 25 years [61], and the

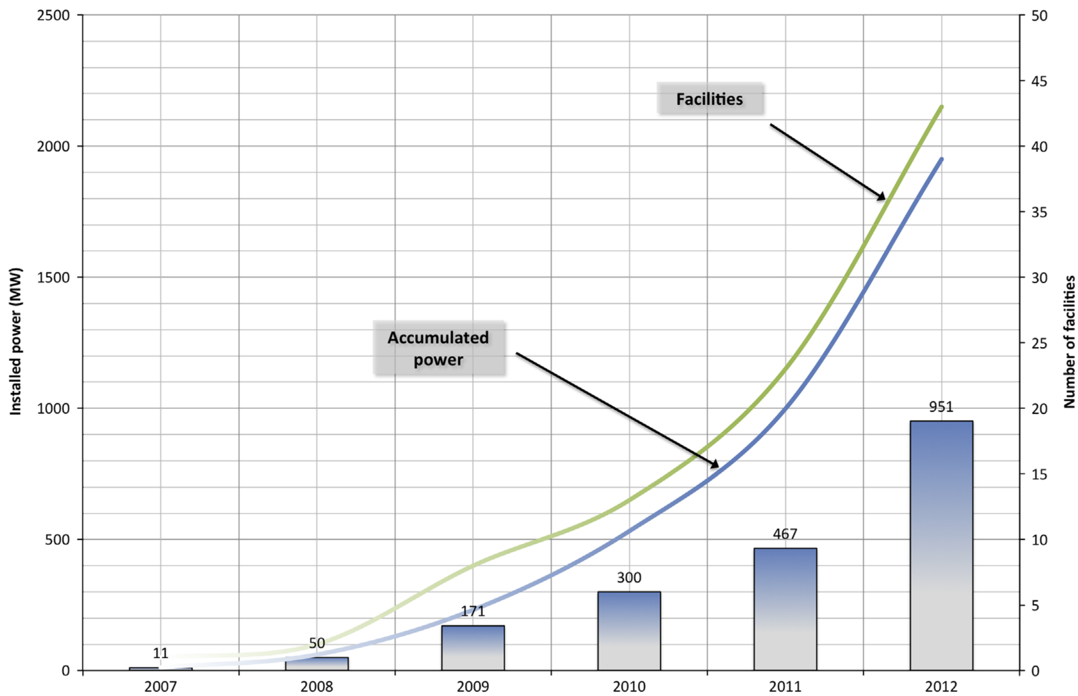

Fig. 8. Development of Spain's installed photovoltaic power and number of facilities over the period 2007–2012.

Royal Decree-Law 14/2010 [62] has established retroactive measures in existing installations, limiting the equivalent hours of operation through the right to receive the originally recognised economic regime. These changes have caused losses of up to 30% of expected revenues in 2011, 2012, and 2013, and losses of 10% after 2014. The industry has experienced a crisis and legal uncertainties of such a great magnitude that Spain has ceased to be one of the strongest countries in the PV sector.

According to the forecasts made by PER for 2011–2020, Spain should have been producing 7250 MW of PV by 2020, but an analysis of the latest data, as shown in Fig. 7, indicates the impossibility of achieving this goal due to the industry's near-zero growth rate since 2009. Due to the inertia of these trends, the only facilities commencing operations have been those that were already built or near completion at the initiation of Decree 14/2010.

3.1.2. *Photothermal solar energy*

Solar thermoelectric technology is still in its start-up phase despite the existence of experimental plants since the 1980s. Spain is the world leader in the commercial deployment of concentrating solar thermal power (CSTP) plants and their technical development [63]. At the same time, Spain is also the world leader in the production of electrical energy via solar thermal power plants, followed by the United States [64]. By the end of 2012, the country produced 1950 MW in 43 facilities, spread mainly over its southern regions where the sun is most abundant (Andalusia, Extremadura, Castilla–La Mancha, and Murcia) [65]. Unlike PV technology, the expansion of solar thermal power is expected to continue because, according to National Energy Commission records, there were requests for 15,563 MW of access to the electricity network (and submitted endorsements) by the end of 2010 [64]. Fig. 8 shows the development of the annual installed power and the total accumulated power in Spain that was connected to the electrical grid by 2012 and the number of facilities connected to the network. The growth rate is still rising despite the legal renewable energy regulations that have been affecting the PV industry since 2008.

Virtually all of Spain's power plants use parabolic trough technology, while only three use solar power towers and one (generating 1.4 MW) uses Fresnel reflectors. Approximately two-thirds of the plants possess 7.5 h of storage [64]. Following reference [65], storage capacity data is only available for 23 of 48 plants. From these 23, only 14 of them have 7.5 h of storage, which is about two-thirds. The demand for photothermal coverage has not yet become significant compared to the other technologies making up the energy mix, although its contribution increased significantly in 2010 and 2011, having reached values close to 1.5% in the summer of 2011. If the provisions of the Plan of Renewable Energy are met, the electricity generated by solar thermal power plants will represent 3% of the Spanish total by 2020, resulting in 14,379 GW h of power with approximately 4800 MW installed. These values appear to be attainable in light of this technology's development in Spain.

3.2. *Wind energy*

Wind energy, the fastest-growing form of sustainable energy, has surmounted many of the issues associated with more conventional fuels, making it not simply an alternative but a viable, mainstream form of power generation [66]. Spain has been a leader in the deployment of wind energy. Spanish wind turbine manufacturers are international leaders, being among the world's 10 largest manufacturers and commanding a joint market share of 16.4% in 2002 [67]. Of the renewable energy sources, wind energy has experienced the greatest growth in Spain during the last decade. The diffusion of on-shore wind power over the period 1995–2004 has been described as impressive and made Spain the second in wind energy installed capacity, behind only Germany and on par with the US [67]. In just 12 years, the contribution of wind energy has gone from being considered insignificant to playing a substantial role in the country's electrical balance. At the end of 2012, wind had generated approximately 22,622 MW of power in Spain, with an electrical output above 48,212 GW h and met approximately 18% of the total national electricity demands, having occasionally surpassed 21% of monthly demands and even 60% coverage in terms of hourly delivery. Fig. 9 shows the annual

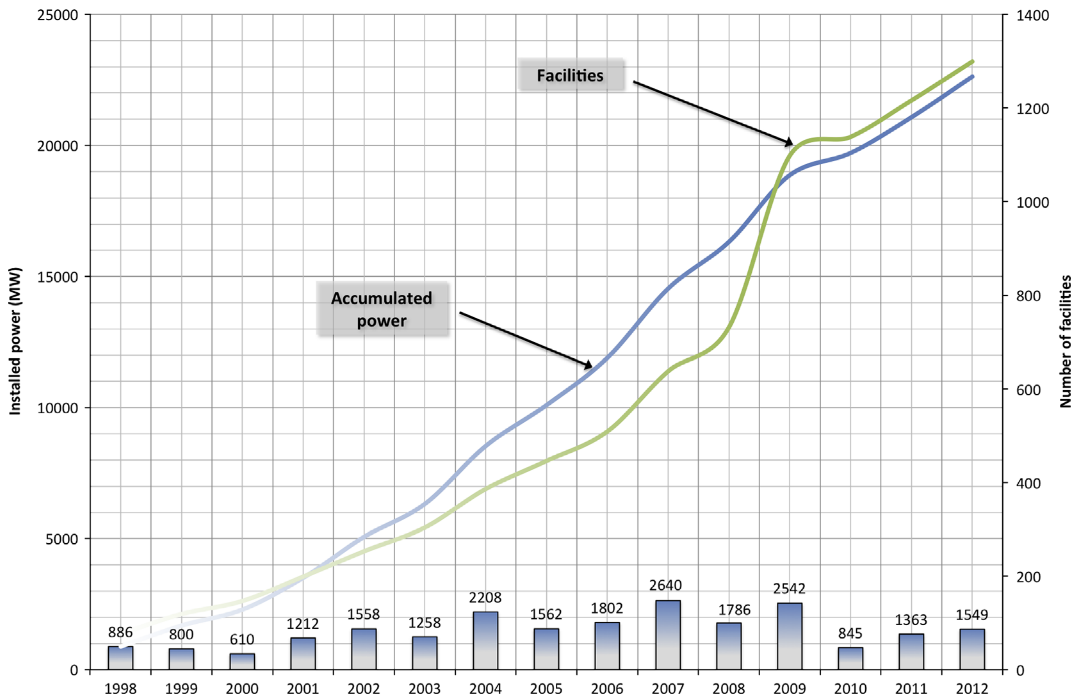

Fig. 9. Development of installed wind power and number of facilities over the period 1998–2012.

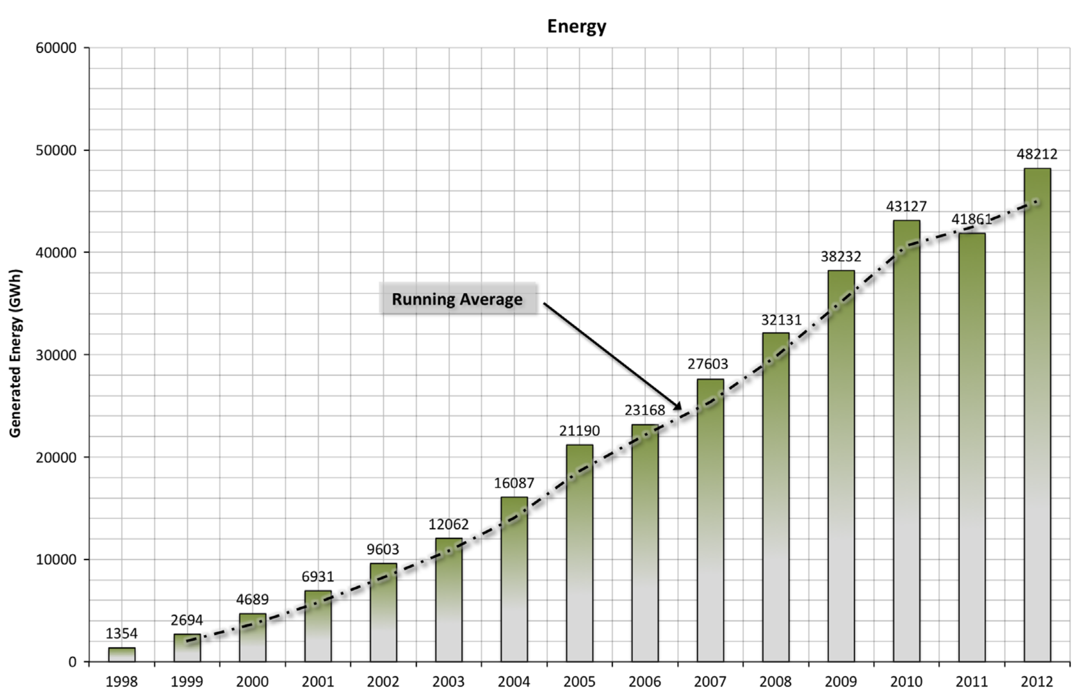

Fig. 10. Development of the wind energy generated during the period 1998–2012.

development of installed wind power, the total accumulated network connections in Spain until 2012, and the number of wind farms connected to the network, which reached 1299 in 2012. The historical installed peaks in power occurred in the years 2007 (2640 MW) and 2009 (2542 MW).

Fig. 10 shows the development of energy generated by wind farms over the period 1998–2012. The figure shows a clear linear increasing trend, as is also the case with installed wind power, which reached its historical peak in 2012.

However, as is the case with the solar sector, wind power has been no stranger to legal changes produced in the last few years, so unfavourable trends in the increasing exploitation of wind resources are expected. This fact has been aggravated by the publication, in early 2012, of the Royal Decree-Law 1/2012 of January 27, which proceeds with the suspension of pre-payment procedures and the suppression of economic incentives for new electric power production facilities using cogeneration, renewable energy sources, and waste. This decree will paralyse the development of new wind power in Spain for the next few years.

Even so, Spain has maintained its status as the country with the fourth largest installed wind power capacity, after China, the USA, and Germany [68]. China, the USA, Germany, Spain, and India are currently the world's top five wind-power-producing countries, and together they share 74% of global installed capacity [69]. At the

regional level, the communities of Castilla–Leon, Castilla–La Mancha, Galicia, and Andalusia have the most installed power (more than 70% of the Spanish total). A study has shown the possibility of meeting a 90% coverage target (indicating practical electrical self-sufficiency) by 2010 in Galicia [70]. The future is uncertain, particularly in terms of meeting the commitment to install 35,750 MW by 2020, with production objectives of 55,604 GW h in 2015 (55,538 GW h onshore and 66 GW h offshore, which would imply an electricity demand coverage level of 17%) and 72,556 GW h in 2020 (70,734 GW h onshore and 1822 GW h offshore, with a demand coverage of 20%). Despite the fact that Spanish wind power potential has been valued at 330 GW (for land-based facilities), given the current situation of regulatory uncertainty, which is paralysing the installation of new power, it will be difficult to predict whether these objectives will be met.

Table 2
Electrical energy generated by biomass in TW h [Eurobserver: http://www.eurobserv-er.org/pdf/baro212biomass.pdf].

Country	Year 2010	Year 2011
Germany	10,730	11,539
Finland	10,570	9968
Sweden	10,260	9641
Poland	5906	7101
United-Kingdom	5252	6137
Netherlands	4197	3977
Austria	3893	3928
Denmark	3314	3064
Spain	2508	2937
Belgium	2904	2904
Italy	2260	2522
Portugal	2225	2467
France	1530	1538
Hungary	2034	1522
Czech-Republic	1493	1686
Estonia	0730	0730
Slovakia	0682	0614
Ireland	0111	0137
Slovenia	0120	0125
Lithuania	0116	0121
Romania	0110	0110
Bulgaria	0019	0019
Latvia	0009	0013
European-Union	70,972	72,800

3.3. Biomass

The biomass sector encompasses any organic matter capable of producing energy [25]. In particular, the Spanish Association of Standardisation and Certification (Spanish initials AENOR) uses the definition given by the European Technical Specification CEN/TS 14588 to catalogue *biomass* as *any material of biological origin, excluding those that have been covered in geological formations suffering a mineralisation process*. This fact implies that biomass resources come from diverse and heterogeneous sources [71], and this heterogeneity, and the technologies available or in development, allows the obtained energy products to replace any conventional energy, including solid, liquid, or gaseous fuels, for thermal and electrical purposes, such as by gasification [72–74] or combustion [75]. Major subsectors include forest [76], both from agricultural seasonal crops [22] and from pruning [77], industrial [78], and energy crops [79]. Data related to the use of biomass for electric power generation through cogeneration or co-firing systems have placed Spain in a modest position (ninth place) compared to countries in northern Europe such as Sweden, Finland, Germany, Poland, and Austria. However, studies have shown that the combined technical potential of agriculture and forestry residues in Spain is equivalent to 11.25% of the net electrical energy generated in Spain in 2008 [76]. For example, Germany had approximately 440 biomass power plants using solid biomass in operation at the end of 2011 [80].

Table 2 provides data on power generation from biomass for 2010 and 2011.

Fig. 11 shows the development of installed electrical power obtained from biomass in recent years. The trend has been stable, with a significant increase in early 2000, but biomass is not very relevant to the country's global renewable energy use and is clearly inferior to the influence of solar and wind technologies. The degree of compliance with the objectives stated in the plan for

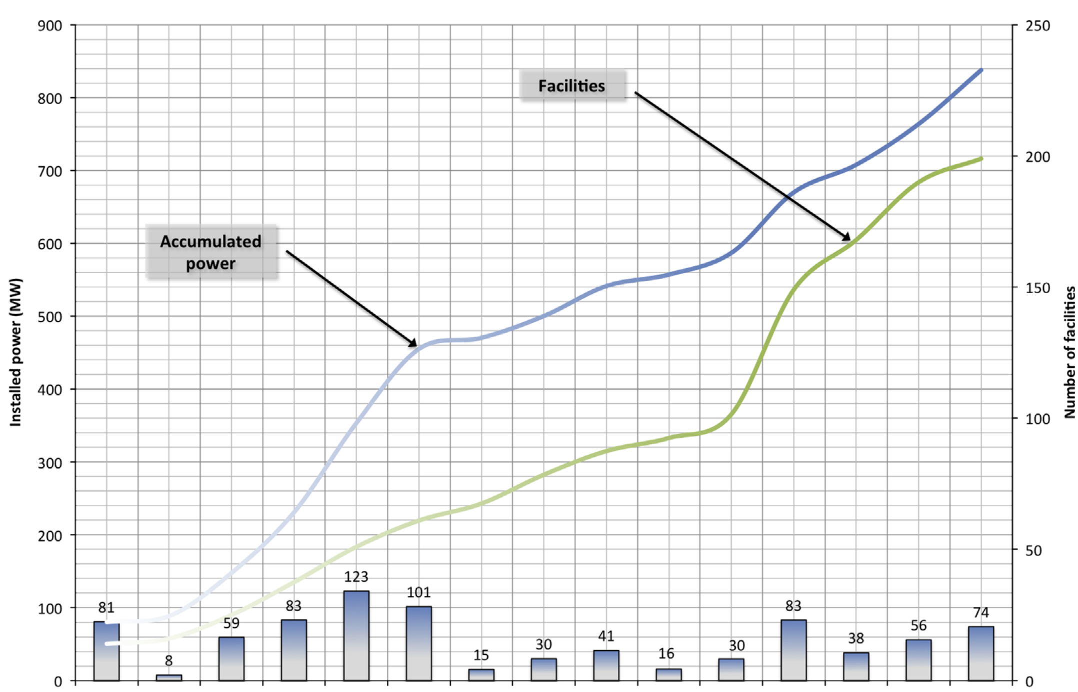

Fig. 11. Installed electric power from biomass.

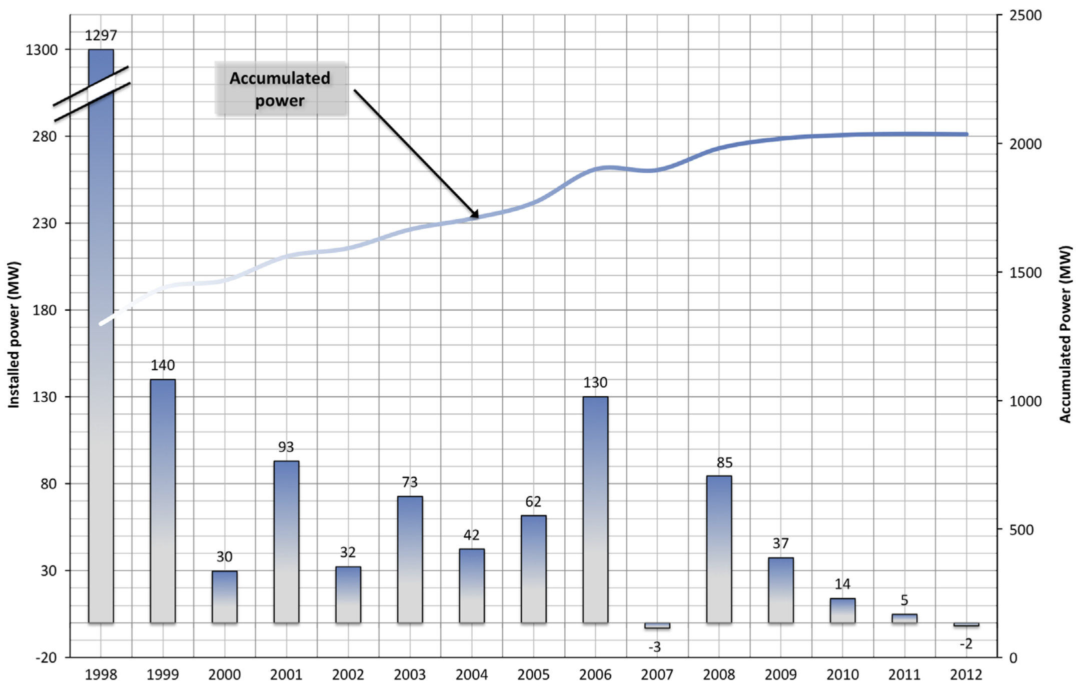

Fig. 12. Development of hydropower in Spain.

expanding renewable energies by 2010 (2039 MW) has been insufficient and is yet to be reached in 2012. Only 839 MW out of the 2039 MW planned for 2010 have been installed, prompting a review of the objectives in the 2011–2020 plan in a manner that will provide for a share of the 1162 MW target by 2015 and the 1950 MW target by 2020.

3.4. Hydropower

Hydropower is dependent on a country's geography [81]. Spain has a significant, consolidated hydroelectric generation system resulting from a long historical tradition of hydropower development due to the country's terrain and a large number of dams. The total capacity of the country's reservoirs is 55,000 H m^3, and 40% of that capacity corresponds to hydroelectric dams, of which Spain has one of the highest proportions in Europe and the world.

Spain ranks fifth in hydroelectric power at the European level, after Sweden, France, Austria, and Italy [82]. In terms of installed hydroelectric power plants with less than 10 MW capacity (small hydropower, or SHP), Spain ranks in third place compared to the rest of the European Union countries. In 2011, its total installed hydropower measured 18,682 MW, of which 1974 MW (10.6%) was SHP [82]. Under Spanish law, hydroelectric plants with less than 10 MW of capacity are considered within the Special Regime, as are any other renewable energies (Royal Decree 661/2007). Over 90% of Europe's installed small hydropower capacity is concentrated in six of the EU-27 member states: Italy, France, Spain, Germany, Austria, and Sweden [81]. Fig. 12 shows the development of hydroelectric power in Spain from 1998 until 2012, and Fig. 13 depicts the development of generated energy. It is interesting to note how the production of energy rises and falls depending on annual rainfall. For example, 2010 was a very rainy year in Spain, resulting in a peak production of 6748 GW h, in contrast to 2011 and 2012, when rainfall was lower and production dropped to 5280 GW h and 4620 GW h, respectively. On the other hand, the country's installed capacity has been essentially stable in the last few years. Only 19 MW have been put into operation in the past three years (although 2 MW were uninstalled), which brought the total installed power in Spain to 2035 MW by the end of 2012. Therefore, the Renewable Energies Plan 2005–2010 objective of 2199 MW has not been fulfilled. The causes of this low capacity have included the risk arising from this type of project, the increasing complexity of the business, and administrative obstacles that make obtaining permits and licenses for power installation a difficult and costly process in terms of time and resources [83].

The installed forecasts for 2015 and 2020 included in the plan for renewable energies have been updated in the 2011–2020 plan, with more reasonable objectives, to be 2017 MW and 2185 MW, respectively.

3.5. Marine and geothermal energy

Aside from the solar, wind, biomass, and hydraulic sectors, the development of other renewable energy sources has still been very limited in Spain, and production has focussed on demonstration projects with the objective of establishing more efficient prototypes. The two most advanced technologies in this sector have been marine and geothermal energy.

Spain has a long coastline and good wave energy resource that could significantly contribute to its renewable energy mix [84]. While the development of marine technology is still in its infancy, the industry has been primarily focussed on wave and current technology. There are nearly 30 active projects (technological and normative-methodological) in development on the Spanish coast, with an estimated investment of more than 230 million euros. These investments are located mainly in the northern coastal regions of Spain and the Basque Country, Cantabria, Asturias, and Galicia, as well as in the Canary Islands. Numerous studies have demonstrated the potential for marine energy in these areas, such as in Galicia [85], where the annual wave power in the Death Coast area is on the order of 50 kW m^{-1}, and the annual wave energy exceeds 400 MW h m^{-1} [86]. Asturias has offshore average wave power and annual wave energy values exceeding 30 kW m^{-1} and 250 MW h m^{-1}, respectively [87], and the Canary Islands show a similar potential [88]. The Renewable Energies Plan for 2011–2020 has estimated a marine energy production potential of 220 GW h

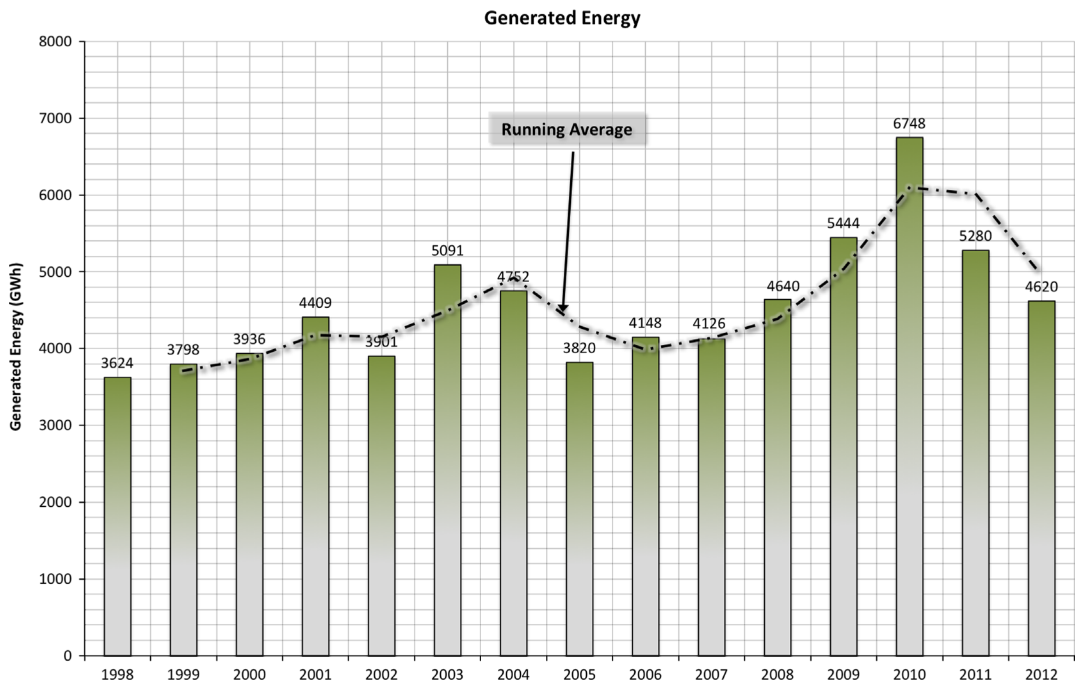

Fig. 13. Development of the energy generated from hydropower in Spain.

and established a series of measures to promote the deployment of 100 MW of marine energy by 2020.

Spanish geothermal technology has also experienced an initial stage of development. Its geothermal potential was investigated in the 1970s by the Geological Survey of Spain (IGME) within the framework of the PEN, which sought to define alternative and local solutions to the world energy crisis that was specifically affecting Spanish economy due to its energy dependency. Until now, geothermal resources have been studied in northwestern area of Spain (the Asturian Central Coal Basin) and two district heating systems have been evaluated, including a low-temperature network (35 °C) for domestic heating and a very low-temperature network (20 °C) for large users, such as shopping centres, that require both heating and cooling. The extrapolation of these results to other mine water reservoirs in Central Asturias has estimated an energy supply capacity close to 260,000 thermal MW h per year [89].

Despite the large estimated geothermal energy resources in Spain (approximately 19,000 MW, of which 1000 MW could be exploited), their exploitation would be expensive and require further technological development. The Renewable Energies Plan of 2011–2020 has set a goal of 50 MW by 2020 and estimated that the first plants will be operational by 2017. There are boreholes and small facilities located at several places across the country, mostly on the Mediterranean coast and near Madrid [90]. Spain installed 22.3 MW by 2007, using 347.2 TJ/yr with a capacity factor of 0.49 [91,92].

4. Review of the legislation regulating renewable energy in Spain

*Law*54/1997 *of the Electricity Sector* [93], enacted on November 27, whose main objective is to regulate the activities aimed at the provision of electrical energy, includes the Special Regime, previously regulated in RD 2366/94, which approves less than 50 MW of power generation with renewable energy on a voluntary basis to provide power to the autonomous communities for their approval. The law also guarantees network facility access in the special regime and introduces an economic regime and production plan to be developed later with successive royal decrees (Royal Decree 2818/1998, of December 23, 436/2004, of March 12, and 661/2007, of May 25). The law also grants power to each autonomous community for legislative and regulatory development and the implementation of the State's basic regulations for electricity. In summary, producers of electricity from renewable energy can secure their access to the network with this legislation, and the technical and economic conditions between producers and distributors are clearly defined.

*Royal Decree*1955/2000 [94], enacted on December 1, governs the approval procedures for production facilities and electricity transportation and distribution networks when their use affects an area larger than an autonomous community, when the electrical power to be installed exceeds 50 MW, or when the transportation or distribution falls outside an autonomous community's territory. In this case, the competent authority is the General Policy Directorate of Energy and Mines, part of the Ministry of Industry, Tourism, and Trade.

*Royal Decree*842/2002 [95], enacted on August 2, approves the electrotechnical regulations for low voltage and their complementary technical instructions (CTI) BT 01 to BT 51, which are applied to all renewable energy generation installations connected to low voltages. Due to its status as a mineral energy resource, geothermal resource utilisation receives a regulatory framework from mining legislation, specifically the law of Mines 22/1973 enacted on July 21 (as amended by Law 54/1980 on November 5). The authorisation of high-enthalpy geothermal applications (electricity generation and/or direct use) is governed by the concessional resources regime of "section D" established in the mining legislation. In this case, the responsibility for legislative development and the implementation of the State's basic laws in the mining regime fall to the autonomous communities.

*Royal Decree*661/2007 [96], enacted on May 25, which regulates electrical energy production activity in the special regime, develops Law No. 54/1997 of the Electricity Sector and establishes a legal and economic regime for cogeneration energy-generating facilities and those that use renewable energy and waste as feedstock, with the fundamental objective of establishing a stable

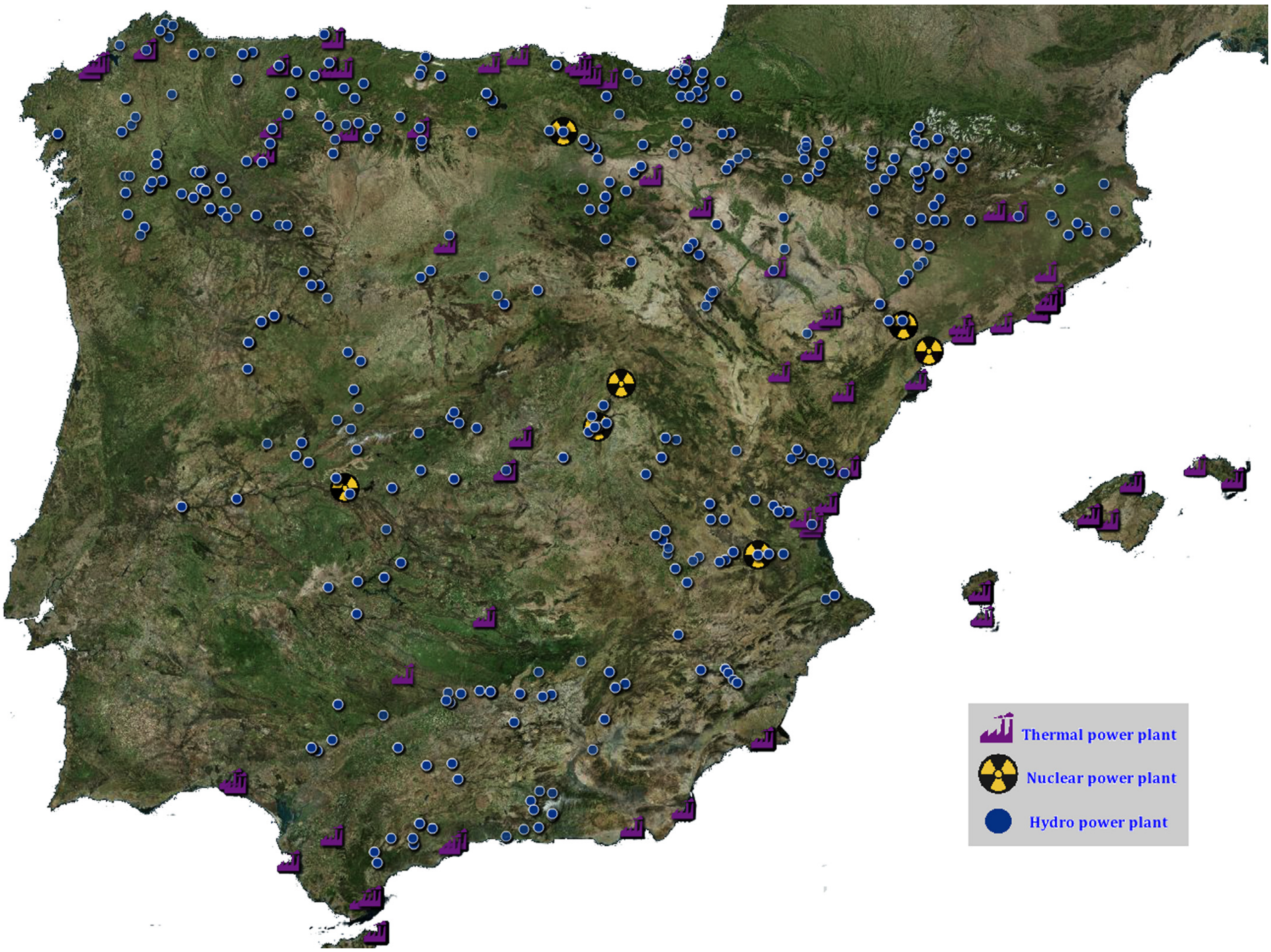

Fig. 14. Location of non-renewable energy production (conventional power plants) in Spain by municipality.

and predictable system that guarantees adequate profitability for electrical energy production in the special regime.

*Royal Decree*1028/2007 [97], enacted on July 20, streamlines the procedure for the introduction of marine generation installations in state jurisdictions, while safeguarding the areas of installation from potential environmental impacts, accounting for the absence of marine experience. Similarly, the decree gathers and integrates the national implementation legislation into a single administrative procedure that guides private initiatives.

*Royal Decree*1578/2008 [98], enacted on September 26, defines a new economic regime for photovoltaic installations and creates a pre-payment register for this technology (PREFO) that affects facilities permanently enrolling in the administrative record of special regime production facilities (RIPRE) from September 2008. This new framework is based on a system of increasing quotas and declining tariffs and is described in more detail in paragraph 4.9.1.

*Royal Decree-Law*6/2009 [99], enacted on April 30, establishes a pre-payment record for special regime facilities that seeks to access conditions of this record as a necessary prerequisite for obtaining the economic regime's payment rights established in Royal Decree 661/2007. The decree applies to facilities and projects management and considers a pre-assignment procedure that accounts for those whose application and endorsement was submitted within the time limits specified by the fourth transitional provision of the Royal Decree 6/2009 enacted on April 30. It also responds to the chronological procedure dependent on the date when administrative authorisation was granted, setting up deadlines for the operation of plants using wind and solar thermoelectric technology. Following Royal Decree 6/2009 enacted on November 24, 2009, a resolution was published on November 19, 2009 that proceeds with the management of projects or facilities on the administrative pre-payment record for the production of electric power and establishes the implementation phases and operation of plants using wind and solar thermoelectric technology.

*Royal Decree*1565/2010 [61], enacted on November 19, regulates and modifies certain aspects related to electric energy production activity in the special regime. The law establishes the technical requirements needed to consider the substantial modification of facilities for the production of electrical energy using cogeneration or wind energy. The decree also modifies the payment system for reactive energy, lays down the conditions for experimental wind technology installations, and, in its third additional provision, allows the granting of the right to additional remuneration for the production market remuneration of electrical energy production facility projects that use innovative solar thermoelectric technology, using a tender procedure for a maximum of 80 MW.

*Royal Decree*1614/2010 [100], enacted on December 7, regulates and modifies certain aspects of the production of electric power using solar thermal technologies and wind. This decree establishes

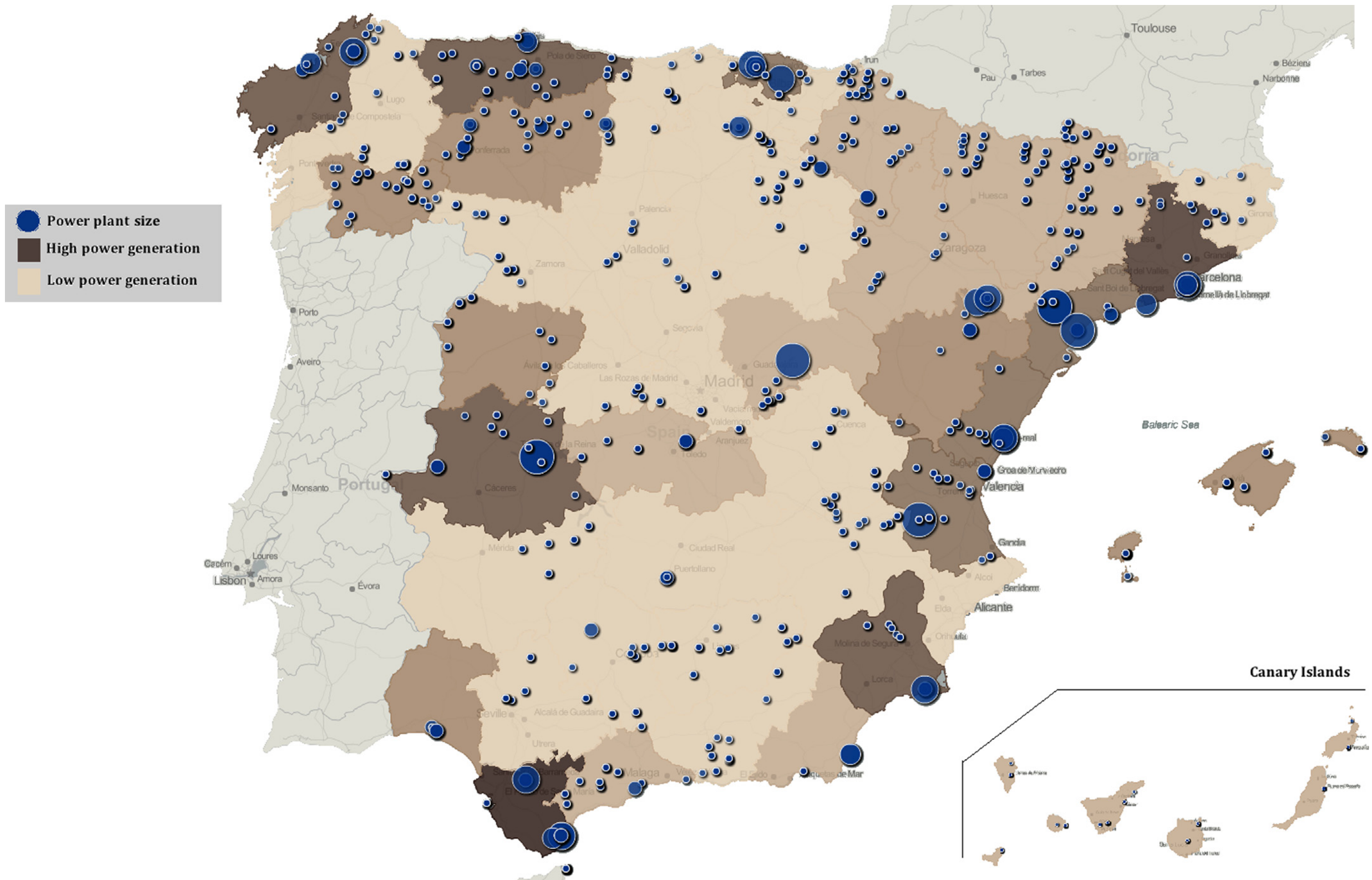

Fig. 15. Location of non-renewable energy production in Spain.

a limit to the equivalent hours of operation with the right to an equivalent premium and a decrease in the premium for wind energy installations.

*Royal Decree-Law*14/2010 [101], enacted on December 23, defines urgent measures for the correction of the electricity sector's tariff deficit. This regulation limits the equivalent operation hours of photovoltaic installations with the right to an economic premium regime. The decree also lays down two constraints, a temporary constraint until December 31, 2013, for the facilities covered by the economic regime defined by Royal Decree 661/2007, and a permanent constraint for all other facilities covered by the economic regime defined by Royal Decree 1578/2008 and Royal Decree 661/2007 after January 1, 2014.

*Law*2/2011 [102], enacted on March 4, incorporates elements of the frameworks for supporting renewable energy that must be present to ensure the sustainability of the sector's future growth, including stability, flexibility, progressive cost internalisation, and prioritisation in the incorporation of those facilities that include technological innovations optimising production efficiency, transport, and distribution, which will lead to increased manageability by reducing greenhouse gas emissions, thus ensuring sufficiency and stability in the energy supply.

*Royal Decree-Law*1/2012 [103], enacted on January 27, this regulation made the suspension of pre-allocation procedures and the removal of economic incentives for new production of electricity from cogeneration, renewable energy and waste; also removed incentives for constructing these facilities, in order to avoid adding new costs to the electrical system.

*Royal Decree-Law*9/2013 [104], enacted on July 12, this regulation authorizes the government to approve a new legal and economic framework for existing production facilities of electricity from renewable energy sources, cogeneration and waste. This framework will articulate a fee which will allow renewable, cogeneration and waste facilities to cover costs to compete in the market on equal level with other technologies and obtain a reasonable return. Another relevant aspect is that the government may determine the right to remuneration for facilities producing electricity from cogeneration or use as primary energy, non-consumable and non-hydro renewable energy, biomass, biofuel or agricultural residues, livestock or services, even if the facilities production of electricity have an installed capacity exceeding 50 MW.

5. Energy production in Spain by province

5.1. Non-renewable energy

The distribution of energy production is a key aspect of a country's development. If generation closely approximates demand, savings are substantial in terms of both energy transportation lines and energy losses in those lines. Fig. 14 shows the conventional nuclear, thermal, and hydroelectric power plants currently operating in Spain; note that hydroelectric power plants higher than 10 MW are considered as non-renewable energy in Spain [96]. The major leverage embodied by hydroelectric plants should be noted, despite Spain being a country with low rainfall, especially in its southern half. It should also be noted that Spain's thermal power plants are located to meet energy production needs where there are no hydraulic power stations and energy demand can be high. Fig. 15 shows the production of conventional energy, where the circle size indicates the level of each plant's

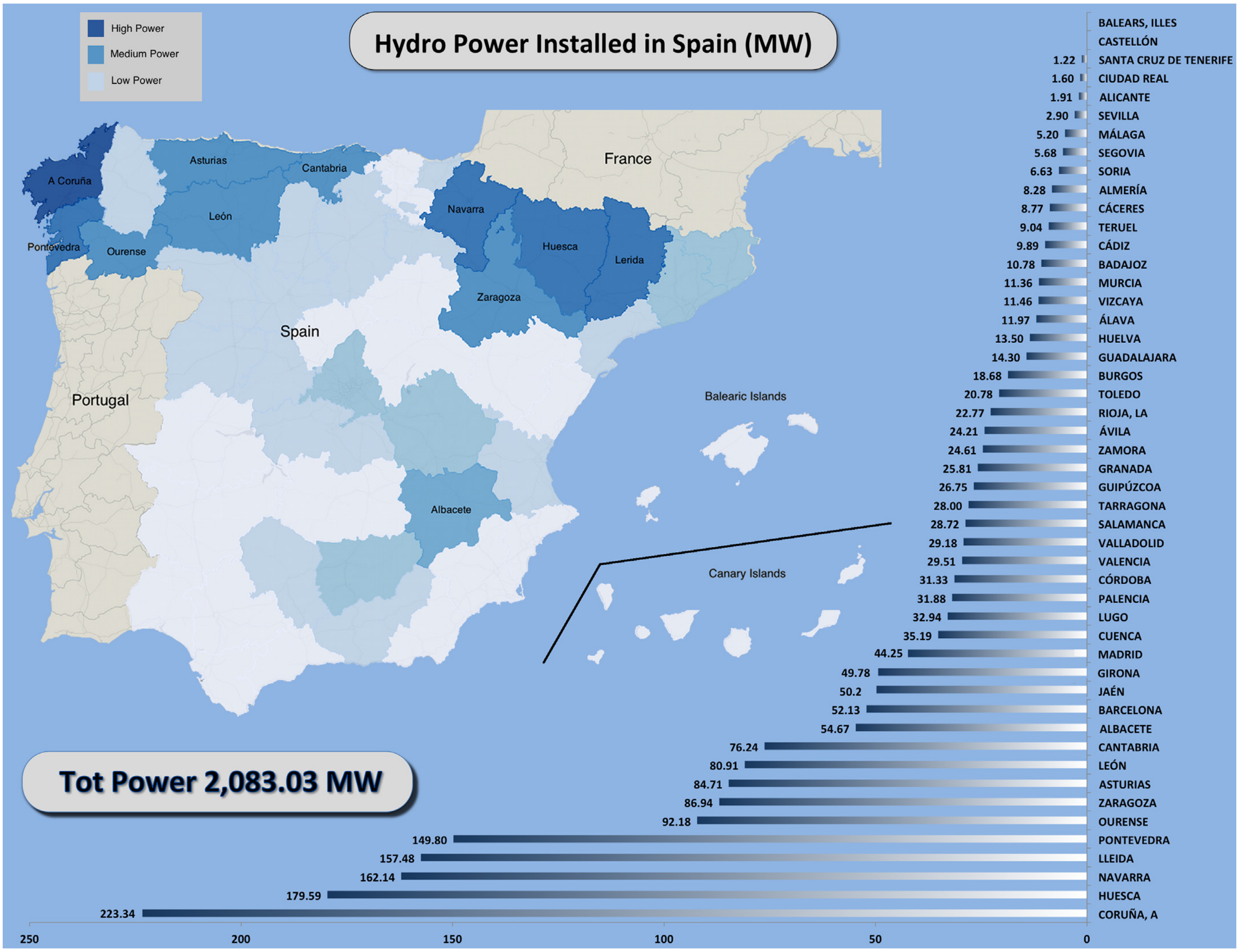

Fig. 16. Location of hydropower production in Spain by province.

installed power, and a map of intensities, coupled with the corresponding energy produced by each province's plants as a background, provides a concept of each province's electricity generation. Nuclear power plants notwithstanding, Spain's conventional energy production is located predominantly on the Mediterranean coast, from Murcia to the border with France, in Cadiz on the southern Atlantic coast, and Galicia, Asturias, and the Basque Country in the north, perhaps to take advantage of the mineral resources (i.e., coal) in these areas of northern Spain.

5.2. Renewable energy

The production of renewable energy must be added to the panorama of conventional energy production. 32.47 GW of renewable energy has been installed in Spain. These renewable energies have not necessarily been developed in areas of high energy demand, but rather where the resources exist. A prime example of this development is Spain's mini-hydraulic energy sector (or SHP), which consists of plants generating less than 10 MW. 2083 MW of SHP power generation have been installed in Spain, and Fig. 16 shows the plants arranged by provinces. These plants are located where the resource is available through a combination of flow and waterfall. Two areas that stand out: the northern provinces of Spain (so-called wet Spain), especially the north coast provinces with the exception of Basque Country, and the Pyrenees provinces bordering France. The island provinces, including the Balearic and Canary Islands, have the least SHP. The hydropower not exploited as a renewable energy, in the sense of small hydropower, is apparently exploited as conventional hydraulic energy, as seen in Fig. 14's data on hydropower plants.

Fig. 17 shows the geographical distribution of solar energy generation in Spain, which totals 6617 MW. It is noted that the possible relationship between the existence of renewable energy resources and their utilisation has not necessarily been achieved for Spanish solar energy. Small areas with identical topographies and latitudes possess the same solar resources, approximately. Navarra, in northern Spain, has significant PV installations (160 MW) for its high latitude, while the south of Spain contains provinces with low solar PV power installation, such as Malaga (52 MW), Jaen (90 MW), and Almeria (84 MW), the latter being one of the areas with the most hours of sunshine throughout the year, one of the highest concentrations of greenhouse crops of the world [105,22,106], and several solar energy research centres [107,108]. The province of Badajoz stands out in southern Spain being the province with the largest installed capacity of 785 MW, followed by Seville (616 MW), Ciudad Real (529 MW), Córdoba (491 MW), and Murcia (475 MW). These data suggest that solar energy has different technologies. The northern of Spain uses photovoltaic energy, which is best suited to the distributed energy paradigm than solar-thermal. In fact, all large solar thermal plants

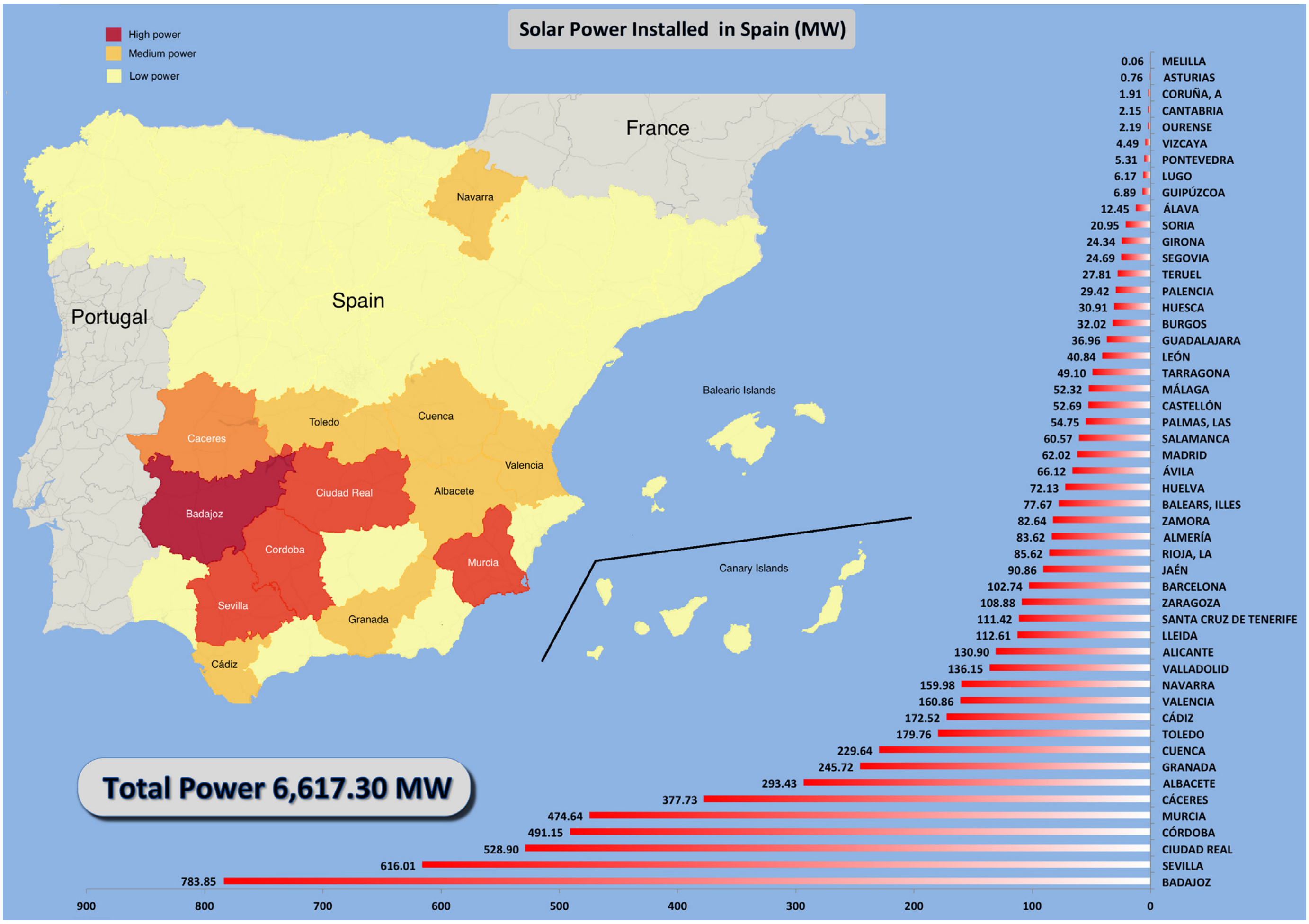

Fig. 17. Location of solar energy production in Spain by province.

are installed in the southern half of the country [65]. It may appear logical to consider photovoltaic and solar thermal energies as a whole from some points of view, but they are radically different technologies which answer to equally different paradigms and users. But also socio-economic factors have led to PV facility's development. A clear example is the normative regulations of autonomous communities such as Navarre, Murcia, and Extremadura (Cáceres and Badajoz).

Regarding wind energy, 23,142 MW have been installed in Spain, the provincial distribution of which is shown in Fig. 18. Two geographically distinct provinces have become the leaders in installed power: Albacete, with more than 2000 MW (which now exceeds the solar power installed in all of Spain), and Burgos, with more than 1800 MW. In third and fourth places are Lugo (1400 MW) and Zaragoza (1375 MW). Navarra was once again among the first provinces to adopt this technology, with 1235 MW installed. It is noteworthy that the provinces of Caceres and Badajoz, which dominate in terms of solar energy, are lagging in wind energy generation, possibly because they do not have wind resources or have focussed strongly on solar energy as a renewable energy source. Spanish wind energy is subject to environmental legislation that limits it [109] by forbidding installation in national and natural parks. There is also a limit to the noise wind turbines that may produce and a minimum distance from population centres and highways [110]. These restrictions have left highly urbanised provinces such as Madrid without this type of energy installation. Cadiz has installed 1316 MW, thanks to the specific wind conditions on the strait of Gibraltar and its Atlantic coast. There are also plans to construct an offshore wind farm in the Sea of Trafalgar, off the coast of Cadiz [111].

Spain produces 636 MW of energy from biomass. Despite being a well-researched topic [18], implementation has not been significant. The only province deriving most of its energy from this resource is Huelva, no doubt due to the utilisation of by-products from the major forestry industry centred on the cultivation of eucalyptus to obtain cellulose [112]. Navarre also leads in biomass energy production with 37 MW, which reinforces the importance of socio-economic factors in autonomous communities supporting renewable energies.

Table 3 shows the result of grouping the production of renewable energy according to autonomous communities that have been able to regulate this type of energy through legislation. The table arranges the communities from highest to lowest installed renewable capacity. The autonomous communities written in capital letters consist of a single province, so their surfaces are smaller. The autonomous community with the most installed renewable resources is Castilla–Leon, with 6305 MW, followed by Andalusia (5446 MW) and Castilla–La Mancha (5288 MW). It should be noted that wind energy plays a very important role because of all the communities that have installed more than 250 MW of renewable energy, 65% is wind and 25% is solar on average. To make a comparison in terms relative to the extent of each autonomous community, we divided the installed power by the area (in square kilometres) of each autonomous community to obtain the last column of Table 3, which makes it evident that Navarra has been the undisputed leader in renewable energy with 153 kW/km^2, followed

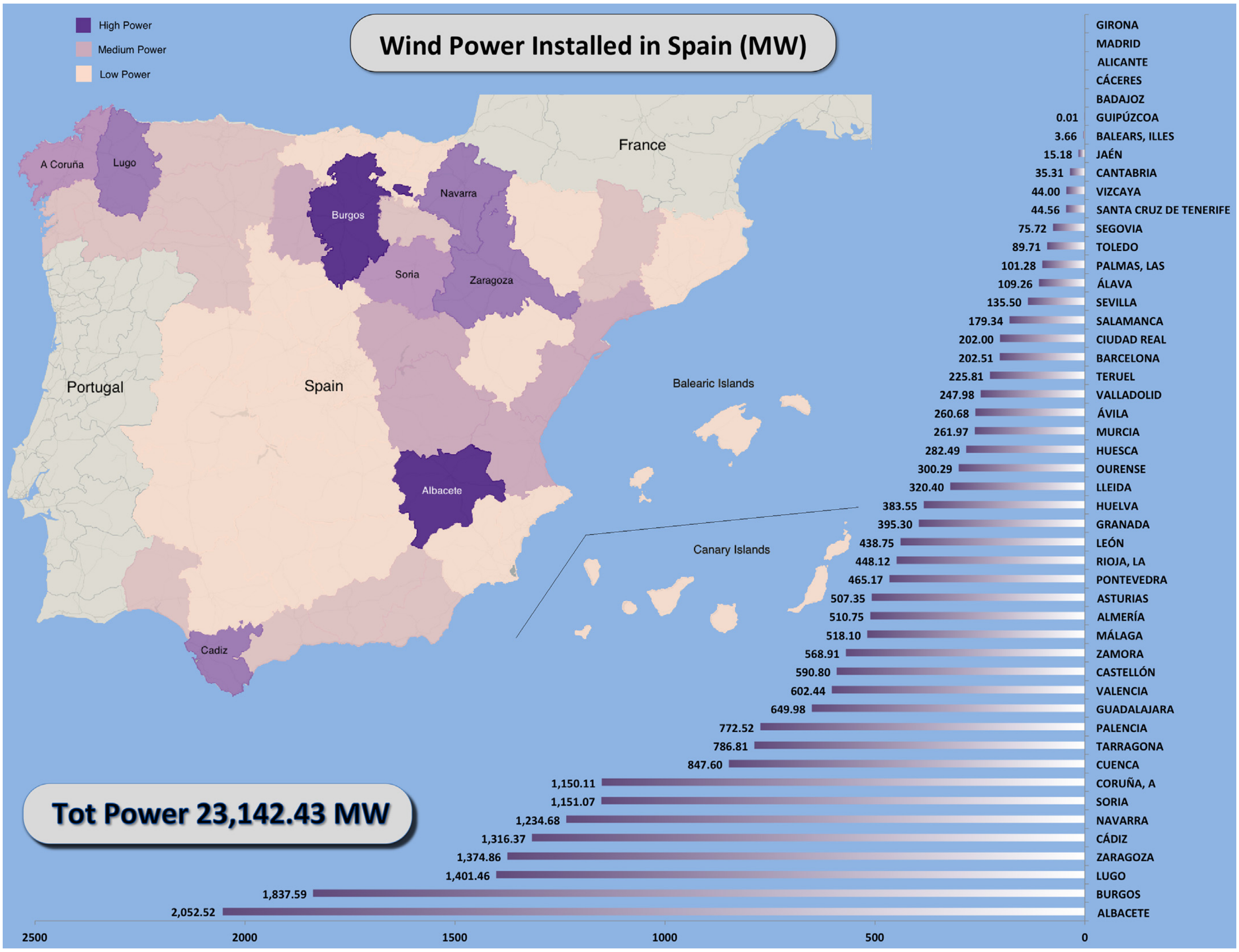

Fig. 18. Location of the wind power production in Spain by province.

Table 3
Renewable energy production by autonomous community (MW): solar, wind, hydro, and biomass.

Autonomous community	Wind	Solar	Hydro	Biomass	Total	Area (km^2)	Average (kW/km^2)	Population	kW/citizen
Castilla and Leon	5532.6	493.4	250.5	28.1	**6305**	94,221	67	2,546,078	2.5
Andalucia	3274.8	1824.3	147.1	199.7	**5446**	87,598	62	8,449,985	0.6
Castilla–La Mancha	3841.8	1268.7	126.5	50.9	**5288**	79,462	67	2,121,888	2.5
Galicia	3317.0	15.6	498.2	39.1	**3870**	29,574	131	2,781,498	1.4
Aragon	1883.2	167.6	275.6	6.2	**2333**	47,720	49	1,349,467	1.7
Cataluña	1309.7	288.8	281.2	52.2	**1932**	32,113	60	7,570,908	0.3
NAVARRA	1234.7	160.0	162.1	36.8	**1594**	10,390	153	644,566	2.5
C. Valenciana	1193.2	344.4	31.4	17.3	**1586**	23,255	68	5,129,266	0.3
Extremadura	0.0	1161.6	19.6	17.1	**1198**	41,635	29	1,108,130	1.1
MURCIA	262.0	474.6	11.4	4.8	**753**	11,313	67	1,474,449	0.5
ASTURIAS	507.4	0.8	84.7	86.0	**679**	10,604	64	1,077,360	0.6
RIOJA, LA	448.1	85.6	22.8	4.3	**561**	5045	111	323,609	1.7
Islas Canarias	145.8	166.2	1.2	3.7	**317**	7447	43	2,118,344	0.1
Pais Vasco	153.3	23.8	50.2	26.5	**254**	7235	35	2,193,093	0.1
MADRID	0.0	62.0	44.2	42.6	**149**	8028	19	6,498,560	0.0
CANTABRIA	35.3	2.1	76.2	12.9	**127**	5327	24	593,861	0.2
BALEARS, ILLES	3.7	77.7	0.0	2.1	**83**	4992	17	1,119,439	0.1
MELILLA	0.0	0.1	0.0	0.0	**0**	13	5	80,802	0.0
Total or average	**23,142.4**	**6617.3**	**2083.0**	**630.2**	**32,473**	**505,972**	**59**	**47,181,303**	**0.7**

by Galicia (131 kW/km^2) and La Rioja (111 kW/km^2). The national average is 59 kW/km^2. Although the autonomous communities have been assumed leaders in renewable energy, the table shows that they do not lead in installed power density.

Spain has more than 47 million inhabitants, and the population of autonomous community is also presented in Table 3. Calculating the installed renewable energy power per capita for each autonomous community, Spain generates an average of 0.7 kW per

capita. There are three autonomous communities (Castilla–Leon, Castilla–La Mancha, and Navarra) with a very high average of 2.5 kW per capita, while those with an average above 1.4 kW per capita include Galicia (1.4), Aragon (1.7), and La Rioja (1.7). Those communities viewed as leaders in installed renewable capacity, such as Andalusia, which ranked second in installed power per capita (0.6), do not occupy a prominent place on this list.

Table 4
Allocation registrations for renewable energy by autonomous community (MW): solar, wind, hydro, and biomass.

Autonomous Community	Wind	Solar	Hydro	Biomass	Total
Castilla and Leon	4949.03	0.29	4.41	0.00	4953.72
MURCIA	4746.61	1.76	3.02	0.50	4751.89
Castilla–La Mancha	3461.80	1.04	1.93	0.00	3464.77
Extremadura	1227.70	99.84	0.00	0.00	1327.54
Cataluña	1233.67	0.07	0.94	0.00	1234.67
Aragon	1038.58	50.01	1.95	0.50	1091.04
Andalucia	801.20	2.39	0.00	0.00	803.59
Comunidad Valenciana	618.27	0.44	0.08	0.00	618.79
RIOJA, LA	143.80	0.08	0.00	0.00	143.88
ASTURIAS	106.10	0.02	3.06	0.00	109.18
MADRID	94.01	1.59	0.00	0.00	95.60
Galicia	38.08	0.00	1.28	0.00	39.35
BALEARS, ILLES	34.89	0.01	0.00	0.00	34.90
NAVARRA	29.25	0.07	1.00	0.50	30.82
Pais Vasco	6.80	0.00	2.70	0.00	9.50
CANTABRIA	0.00	0.77	0.00	0.00	0.77
Islas Canarias	0.00	0.52	0.00	0.00	0.52
MELILLA	0.00	0.00	0.00	0.00	0.00
Total	18,529.78	158.90	20.35	1.50	18,710.53

Table 4 provides a look at previous registrations or allocations to assess the future of each community's renewable energy generation. Wind energy dominates this table. Castilla–Leon (4953 MW), Murcia (4751 MW), and Castilla–La Mancha (3464 MW) have the most allocated facilities, but Extremadura, which has been one of the leaders in solar and has no installed wind energy, occupies fourth place with 1327 MW, of which 1227 MW are from wind (Fig. 19).

New solar energy installations have almost disappeared from Spain's energy forecast, no doubt due to changes in energy rates. Fig. 20 shows the status of installed power versus allocation in the two major renewable energy sectors, solar and wind. The figure shows that wind energy will continue growing in the near future. Given the current energy regulation in Spain, this energy appears to be more sustainable in the medium term.

6. Electrical energy balance sheet in Spain: production and consumption

Until now, renewable energy has contributed to alleviating the energy shortfall Spain is currently experiencing. Although the country's electricity production balance is positive, the location

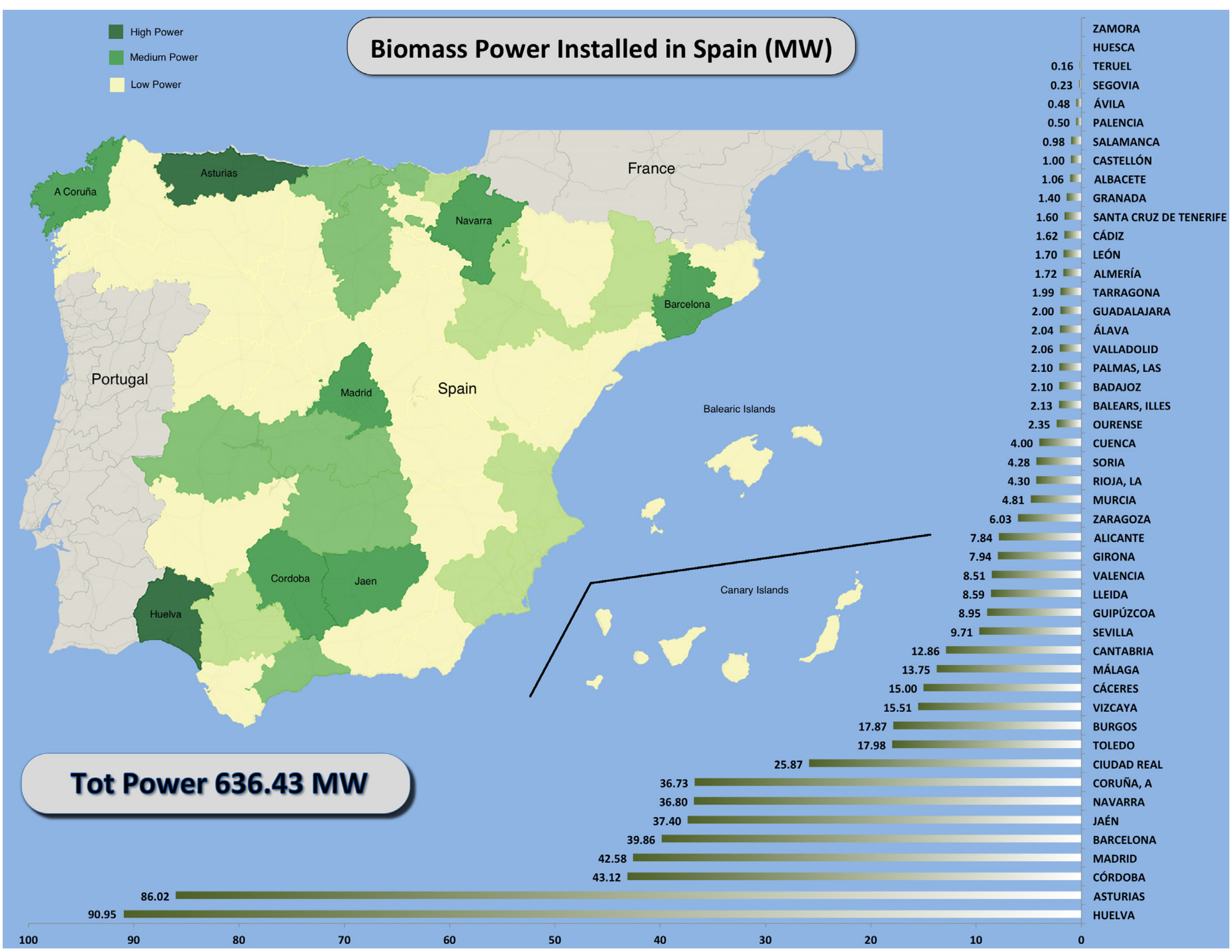

Fig. 19. Location of biomass power production in Spain by province.

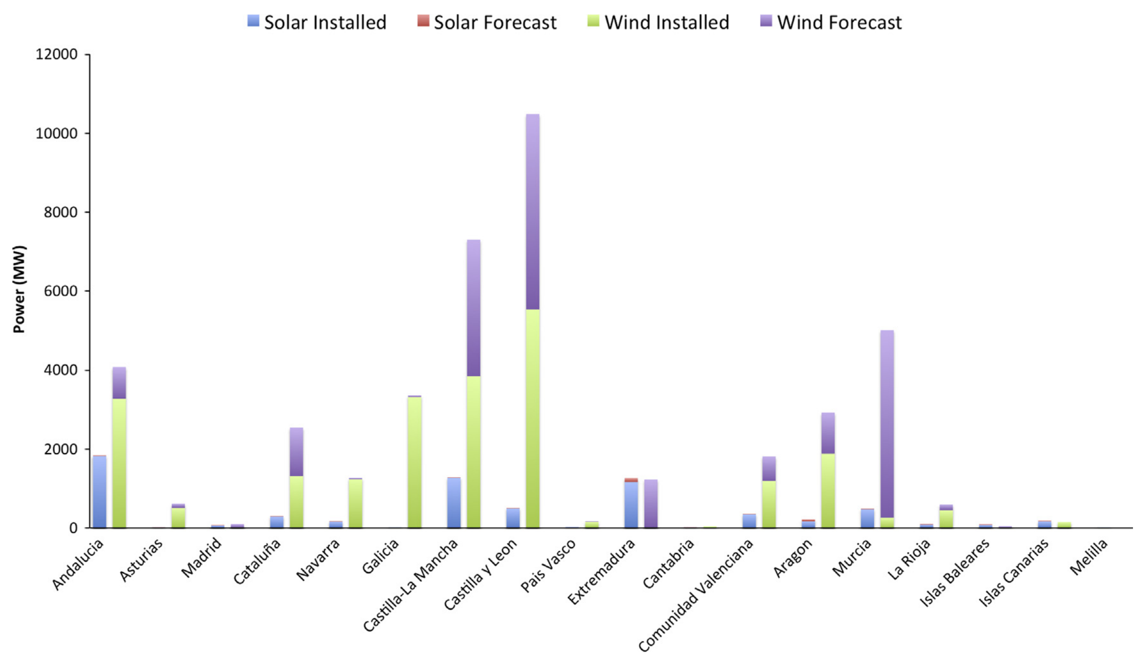

Fig. 20. Status of installed power versus solar and wind energy allocation.

of energy generation and its approximation of potential demand are vitally important. Table 5 shows Spain's energy balance by province, organised according to its growth in energy surplus. Fig. 21 shows the energy balance by province (consumption minus production) using a colour scale to illustrate net energy consumption. The two provinces with the highest energy demands, Barcelona and Madrid, also have large energy deficits. However, the province in third place, Valencia, has an energy surplus. Consumption of electricity occurs along the entire coast, except in the province of Almeria (southeast corner), the Ebro valley and Navarra, and Madrid, leaving central Spain with a lower consumption of 3000 GW h. The average consumption per province is 4.815 GW h, and if the two greatest consumer provinces are removed from this average (Madrid and Barcelona), it becomes 3825 GW h. The production average over all provinces is 5502 GW h.

Insular provinces have a slight surplus of electricity, which will not limit their growth in the medium term. On the other hand, the leader in installed solar power, Badajoz, is still lagging in electric power generation by 20.26 GW h, even though this province does not have a large population or a large industrial sector demanding energy. In general, the southern half of Spain, where most of the country's solar energy is installed, has not resolved its electricity needs: Seville and Cordoba, which lead the nation in solar energy production, remain in deficit.

On the other hand, the leaders in installed wind power, Burgos, Albacete, La Coruna, and Cadiz, have a surplus. It is also of interest that most of the provinces bordering with Portugal have a surplus.

Consumption can be displayed as a function of population to determine the provinces' energy needs based on their population and industrialisation. When depicted in this way, Spain consumes 5.6 MW h per capita and produces 10.1 MW h per capita on average. Sparsely populated and industrialised provinces consume the most (MW h per inhabitant), including Lugo (14.7), Huesca (10.3), and Tarragona (9.7). On the contrary, the three provinces with the highest net consumption have average values below the average: Madrid (4.5), Valencia (4.8), and Barcelona (5.5). It could be concluded that these highly populated and industrialised have made efficient use of their energy, or that less populated and industrialised areas have been less efficient or cost-effective in terms of their electrical consumption.

Spain has installed 32,472 MW of renewable energy and it has been proven that renewable energy represents 11.6% of the country's primary energy consumption. An initial analysis has shown development over time, highlighting a dramatic increase from 2007 to 2008 in photovoltaic energy due to the legal regulations of a special regime. The installed power of solar energy in Spain is 6617 MW, with the province of Badajoz in first place (785 MW), followed by Seville with 616 MW. The country's energy legislation has been revised, changing its effects on the renewable energy sector, in particular photovoltaics. Solar thermal power is experiencing a stage of growth, but it is not representative of the other technologies comprising the energy mix. However, its contribution has increased significantly in 2010 and 2011, reaching values close to 1.5% of the national total in the summer of 2011. Wind energy is very important in Spain, with 23,142 MW having been installed, and it is the fourth largest country in terms of installed wind power, after China, the USA, and Germany. Wind energy continues to experience a good growth rate, and does not seem to be affected by energy regulations, which has made it the most sustainable renewable energy in Spain. The two provinces with the most wind installation are Albacete, with more than 2000 MW, and Burgos, with more than 1800 MW. Energy generated from biomass has accounted only for 636 MW, led by the province of Huelva, with 91 MW. Spain has only 2083 MW of mini-hydroelectric power, concentrated in the north of the country, the Pyrenees and the northern coast. The production of renewable energy has been grouped by autonomous communities, with Castilla–Leon (6305 MW), Andalusia (5446 MW), and Castilla–La Mancha (5288 MW) leading in installation. However, when looking at geographical area, Navarre is the undisputed leader in renewable energy, with 153 kW/km^2, followed by Galicia (131 kW/km^2) and La Rioja (111 kW/km^2). The national average is 59 kW/km^2 of renewable energy installed for the production of electric energy. In terms of population, 0.7 kW are generated per capita on average. Three autonomous communities have a very high average of 2.5 kW per capita: Castilla–Leon, Castilla–La Mancha, and Navarra, and those with an average above 1.4 kW per capita include Galicia, Aragon, and La Rioja.

Table 5
Data on the production and consumption of energy by province in Spain.

Province	Net consumption (MW h)	Net production (MW h)	Balance (MW h)	Population	Consumption (MW h/citizen)	Production (MW h/citizen)	Balance
MADRID	28,905,351	3,117,906	−25,787,445	6,489,680	4.5	0.5	−4.0
BARCELONA	30,215,608	9,182,454	−21,033,154	5,529,099	5.5	1.7	−3.8
ALICANTE	8,494,539	283,426	−8,211,113	1,934,127	4.4	0.1	−4.2
SEVILLA	8,006,007	1,142,957	−6,863,050	1,928,962	4.2	0.6	−3.6
GUIPUZCOA	5,928,626	1,282,461	−4,646,165	709,607	8.4	1.8	−6.5
GIRONA	4,489,753	792,863	−3,696,890	756,810	5.9	1.0	−4.9
MALAGA	6,294,057	3,000,709	−3,293,348	1,625,827	3.9	1.8	−2.0
CANTABRIA	4,207,451	1,054,819	−3,152,632	593,121	7.1	1.8	−5.3
BADAJOZ	3,211,542	1,184,774	−2,026,768	693,921	4.6	1.7	−2.9
CORDOBA	3,156,342	1,351,567	−1,804,775	805,857	3.9	1.7	−2.2
PONTEVEDRA	3,724,923	1,941,208	−1,783,715	963,511	3.9	2.0	−1.9
VALLADOLID	2,700,228	1,041,472	−1,658,756	534,874	5.0	1.9	−3.1
ALAVA	2,466,400	881,263	−1,585,137	319,227	7.7	2.8	−5.0
GRANADA	3,360,899	1,883,394	−1,477,505	924,550	3.6	2.0	−1.6
JAEN	2,887,928	1,720,090	−1,167,838	670,600	4.3	2.6	−1.7
SEGOVIA	949,890	441,958	−507,932	164,169	5.8	2.7	−3.1
LEON	2,340,095	2,045,183	−294,912	529,799	4.4	3.9	−0.6
VIZCAYA	8,103,610	7,856,788	−246,822	1,155,772	7.0	6.8	−0.2
AVILA	715,381	497,560	−217,821	172,704	4.1	2.9	−1.3
CEUTA	273,886	217,536	−56,350	82,376	3.3	2.6	−0.7
MELILLA	226,143	205,394	−20,749	78,476	2.9	2.6	−0.3
TOLEDO	3,912,606	4,156,174	243,568	707,242	5.5	5.9	0.3
LAS PALMAS	4,727,230	5,006,639	279,409	1,096,980	4.3	4.6	0.3
S.C.TENERIFE	3,562,642	3,931,762	369,120	1,029,789	3.5	3.8	0.4
BALEARES	5,342,822	5,870,099	527,277	1,113,114	4.8	5.3	0.5
LUGO	5,157,975	5,761,326	603,351	351,350	14.7	16.4	1.7
CIUDAD REAL	2,696,650	3,302,189	605,539	530,175	5.1	6.2	1.1
PALENCIA	1,009,446	1,761,213	751,767	171,668	5.9	10.3	4.4
LA RIOJA	1,631,772	2,748,186	1,116,414	322,955	5.1	8.5	3.5
CASTELLON	4,455,205	5,701,863	1,246,658	604,344	7.4	9.4	2.1
CUENCA	966,187	2,415,162	1,448,975	219,138	4.4	11.0	6.6
HUESCA	2,354,113	4,149,409	1,795,296	228,361	10.3	18.2	7.9
MURCIA	7,505,513	9,493,240	1,987,727	1,470,069	5.1	6.5	1.4
LLEIDA	2,467,310	4,645,745	2,178,435	442,308	5.6	10.5	4.9
ALMERIA	2,959,616	5,204,779	2,245,163	702,819	4.2	7.4	3.2
SORIA	586,743	3,073,886	2,487,143	95,223	6.2	32.3	26.1
ASTURIAS	9,669,975	12,500,170	2,830,195	1,081,487	8.9	11.6	2.6
NAVARRA	4,521,947	7,576,076	3,054,129	642,051	7.0	11.8	4.8
TERUEL	949,168	4,106,792	3,157,624	144,607	6.6	28.4	21.8
ALBACETE	2,058,081	5,242,983	3,184,902	402,318	5.1	13.0	7.9
ZAMORA	822,473	4,278,430	3,455,957	191,612	4.3	22.3	18.0
ZARAGOZA	6,468,431	10,161,758	3,693,327	973,325	6.6	10.4	3.8
VALENCIA	12,385,221	17,121,220	4,735,999	2,578,719	4.8	6.6	1.8
SALAMANCA	1,504,311	6,372,768	4,868,457	352,986	4.3	18.1	13.8
BURGOS	2,498,325	7,611,480	5,113,155	375,657	6.7	20.3	13.6
HUELVA	3,255,804	8,635,268	5,379,464	521,968	6.2	16.5	10.3
ORENSE	1,421,149	6,913,524	5,492,375	333,257	4.3	20.7	16.5
LA CORUÑA	7,929,681	14,091,992	6,162,311	1,147,124	6.9	12.3	5.4
GUADALAJARA	1,753,345	9,084,930	7,331,585	256,461	6.8	35.4	28.6
CADIZ	5,835,015	14,057,042	8,222,027	1,243,519	4.7	11.3	6.6
CACERES	1,453,827	18,834,550	17,380,723	415,446	3.5	45.3	41.8
TARRAGONA	7,893,643	31,217,056	23,323,413	811,401	9.7	38.5	28.7
Total or average	250,414,885	286,153,493	35,738,608	47,220,542	5.6	10.1	4.5

7. Conclusions

This work revised the production of energy in Spain, particularly its renewable energy (solar, wind, hydroelectric, and biomass), its development over time, and its geographical distribution by province and autonomous community, which have the legal capacity to create legislation on these energies. Wind energy continues to experience a good growth rate, and does not seem to be affected by regulations, which has made it the most sustainable renewable energy in Spain.

This study illustrated how renewable energies have contributed to alleviating the energy shortfall that Spain has been experiencing. The balance of electricity production has created a positive balance in Spain, with a surplus of 35,738 GW h, by selling electricity to Portugal and Morocco and buying it from France. In terms of the energy balance by province, the two provinces with the highest energy demands, Barcelona and Madrid, also have large energy deficits. The average consumption per province in Spain is 4815 GW h, and in terms of population, Spain consumes 5.6 MW h per capita and produces 10.1 MW h per capita on average. Sparsely populated and industrialised provinces have also experienced the most consumption (MW h per inhabitant), including Lugo (14.7), Huesca (10.3), and Tarragona (9.7). In contrast, the three provinces with the highest net consumption have experienced average values that are below the national average: Madrid (4.5), Valencia (4.8), and Barcelona (5.5). These highly populated and industrialised provinces made more efficient use of their energy, and less populated and industrialised areas were less efficient or cost-effective from an electrical consumption viewpoint. In general, Spain has experienced very uneven growth in renewable energies due to its geography. This uneven growth has not been motivated solely by the existence of renewable energy

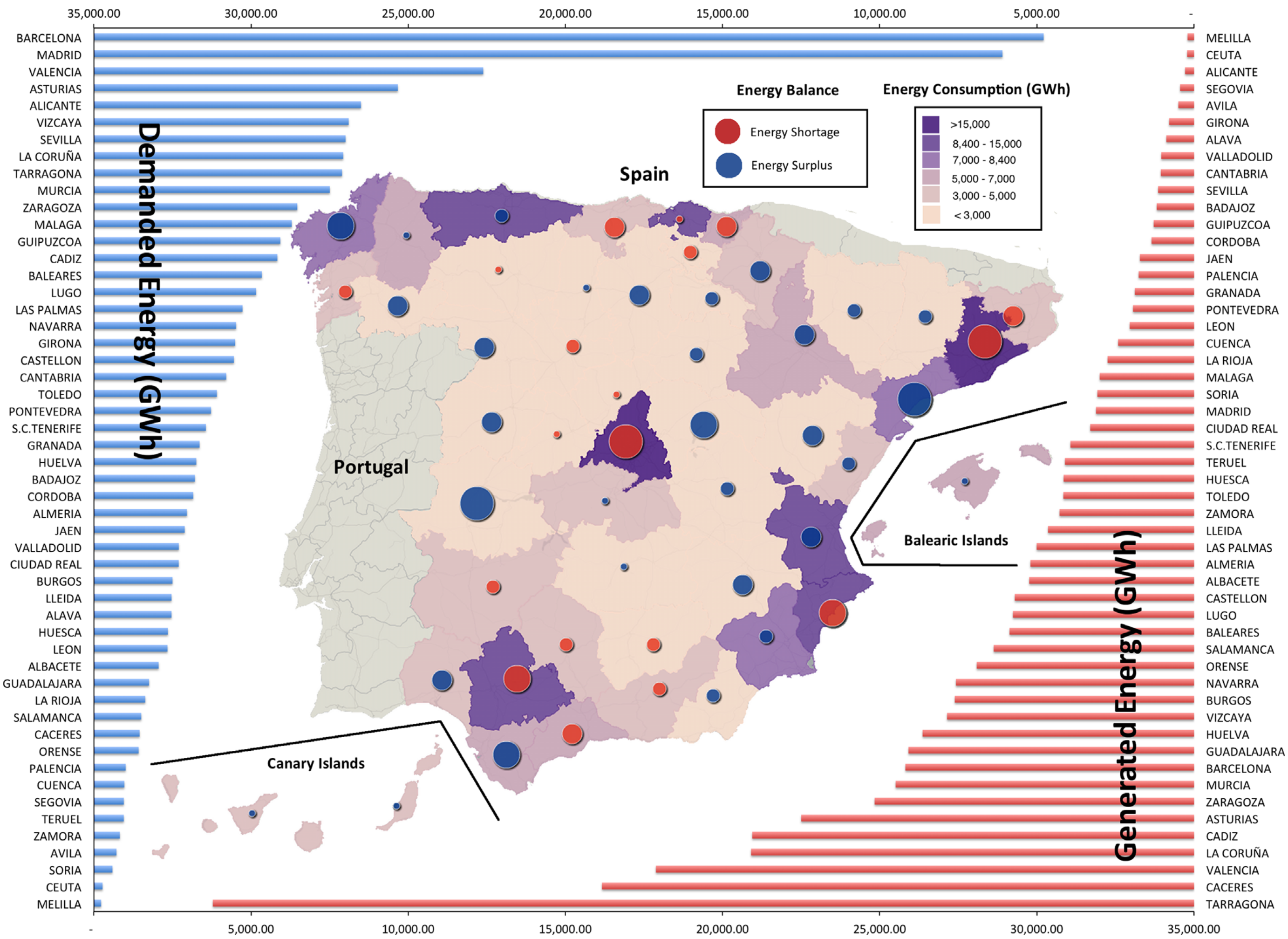

Fig. 21. Production and consumption of total energy per province in Spain. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)

resources, but rather by the locations of autonomous communities within provinces.

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References

[1] Baños R, Manzano-Agugliaro F, Montoya F, Gil C, Alcayde A, Gómez J. Optimization methods applied to renewable and sustainable energy: a review. Renew Sustain Energy Rev 2011;15(4):1753–66 http://dx.doi.org/10.1016/j.rser.2010.12.008. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032110004430⟩.

[2] Aleklett K, Höök M, Jakobsson K, Lardelli M, Snowden S, Söderbergh B. The peak of the oil age—analyzing the world oil production reference scenario in world energy outlook 2008. Energy Policy 2010;38(3):1398–414 http://dx.doi.org/10.1016/j.enpol.2009.11.021. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421509008519⟩.

[3] Friedler F. Process integration, modelling and optimisation for energy saving and pollution reduction. Appl Thermal Eng 2010;30(16):2270–80 http://dx.doi.org/10.1016/j.applthermaleng.2010.04.030. URL ⟨http://www.sciencedirect.com/science/article/pii/S1359431110001936⟩.

[4] Dovì VG, Friedler F, Huisingh D, Klemeş JJ. Cleaner energy for sustainable future. J Clean Prod 2009;17(10):889–95 http://dx.doi.org/10.1016/j.jclepro.2009.02.001. URL ⟨http://www.sciencedirect.com/science/article/pii/S0959652609000250⟩.

[5] Kaygusuz K. Energy and environmental issues relating to greenhouse gas emissions for sustainable development in Turkey. Renew Sustain Energy Rev 2009;13(1):253–70 http://dx.doi.org/10.1016/j.rser.2007.07.009. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032107001190⟩.

[6] Abdelaziz E, Saidur R, Mekhilef S. A review on energy saving strategies in industrial sector. Renew Sustain Energy Rev 2011;15(1):150–68 http://dx.doi.org/10.1016/j.rser.2010.09.003 URL ⟨http://www.sciencedirect.com/science/article/pii/S136403211000290X⟩.

[7] Meadowcroft J. What about the politics? Sustainable development, transition management, and long term energy transitions Policy Sci 2009;42(4):323–40, http://dx.doi.org/10.1007/s11077-009-9097-z URL ⟨http://dx.doi.org/10.1007/s11077-009-9097-z⟩.

[8] Ekholm T, Krey V, Pachauri S, Riahi K. Determinants of household energy consumption in India. Energy Policy 2010;38(10):5696–707 http://dx.doi.org/10.1016/j.enpol.2010.05.017. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421510003885⟩.

[9] Kumar A, Kumar K, Kaushik N, Sharma S, Mishra S. Renewable energy in India: current status and future potentials. Renew Sustain Energy Rev 2010;14(8):2434–42 http://dx.doi.org/10.1016/j.rser.2010.04.003. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032110001140⟩.

[10] Kale RV, Pohekar SD. Electricity demand supply analysis: current status and future prospects for Maharashtra, India. Renew Sustain Energy Rev 2012;16(6):3960–6 http://dx.doi.org/10.1016/j.rser.2012.03.008. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032112001888⟩.

[11] Price L, Levine MD, Zhou N, Fridley D, Aden N, Lu H, et al. Assessment of China's energy-saving and emission-reduction accomplishments and opportunities during the 11th five year plan. Energy Policy 2011;39(4):2165–78 http://dx.doi.org/10.1016/j.enpol.2011.02.006. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421511000814⟩.

[12] Lora E, Andrade R. Biomass as energy source in Brazil. Renew Sustain Energy Rev 2009;13(4):777–88 http://dx.doi.org/10.1016/j.rser.2007.12.004. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032108000270⟩.
[13] Pao H-T, Tsai C-M. Modeling and forecasting the {CO_2} emissions, energy consumption, and economic growth in Brazil. Energy 2011;36(5):2450–8 http://dx.doi.org/10.1016/j.energy.2011.01.032. URL ⟨http://www.sciencedirect.com/science/article/pii/S0360544211000338⟩.
[14] Pereira MG, Freitas MAV, da Silva NF. Rural electrification and energy poverty: empirical evidences from Brazil. Renew Sustain Energy Rev 2010;14(4):1229–40 http://dx.doi.org/10.1016/j.rser.2009.12.013. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032109003025⟩.
[15] Zhang X, Kumar A. Evaluating renewable energy-based rural electrification program in Western China: emerging problems and possible scenarios. Renew Sustain Energy Rev 2011;15(1):773–9 http://dx.doi.org/10.1016/j.rser.2010.08.023. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032110002765⟩.
[16] Kamalapur G, Udaykumar R. Rural electrification in India and feasibility of photovoltaic solar home systems. Int J Electr Power Energy Syst 2011;33(3):594–9 http://dx.doi.org/10.1016/j.ijepes.2010.12.014. URL ⟨http://www.sciencedirect.com/science/article/pii/S0142061510002310⟩.
[17] Oda H, Tsujita Y. The determinants of rural electrification: the case of Bihar, India. Energy Policy 2011;39(6):3086–95 http://dx.doi.org/10.1016/j.enpol.2011.02.014. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421511000905⟩.
[18] Manzano-Agugliaro F, Alcayde A, Montoya F, Zapata-Sierra A, Gil C. Scientific production of renewable energies worldwide: an overview. Renew Sustain Energy Rev 2013;18:134–43 http://dx.doi.org/10.1016/j.rser.2012.10.020. URL ⟨http://www.sciencedirect.com/science/article/pii/S136403211200562X⟩.
[19] Denny E. The economics of tidal energy. Energy Policy 2009;37(5):1914–24 http://dx.doi.org/10.1016/j.enpol.2009.01.009. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421509000408⟩.
[20] Hernández-Escobedo Q, Manzano-Agugliaro F, Zapata-Sierra A. The wind power of Mexico. Renew Sustain Energy Rev 2010;14(9):2830–40 http://dx.doi.org/10.1016/j.rser.2010.07.019. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032110001991⟩.
[21] Cruz-Peragon F, Palomar J, Casanova P, Dorado M, Manzano-Agugliaro F. Characterization of solar flat plate collectors. Renew Sustain Energy Rev 2012;16(3):1709–20 http://dx.doi.org/10.1016/j.rser.2011.11.025. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032111005715⟩.
[22] Callejón-Ferre A, Velázquez-Martí B, López-Martínez J, Manzano-Agugliaro F. Greenhouse crop residues: energy potential and models for the prediction of their higher heating value. Renew Sustain Energy Rev 2011;15(2):948–55 http://dx.doi.org/10.1016/j.rser.2010.11.012. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032110003813⟩.
[23] Singh R, Setiawan AD. Biomass energy policies and strategies: harvesting potential in India and Indonesia. Renew Sustain Energy Rev 2013;22:332–45 http://dx.doi.org/10.1016/j.rser.2013.01.043. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032113000749⟩.
[24] Tsai W-T. Analysis of the sustainability of reusing industrial wastes as energy source in the industrial sector of Taiwan. J Clean Prod 2010;18(14):1440–5 http://dx.doi.org/10.1016/j.jclepro.2010.05.004. URL ⟨http://www.sciencedirect.com/science/article/pii/S0959652610001770⟩.
[25] Manzano-Agugliaro F, Sanchez-Muros M, Barroso F, Martínez-Sánchez A, Rojo S, Pérez-Bañón C. Insects for biodiesel production. Renew Sustain Energy Rev 2012;16(6):3744–53 http://dx.doi.org/10.1016/j.rser.2012.03.017. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032112002006⟩.
[26] Rosiek S, Batlles FJ. Renewable energy solutions for building cooling, heating and power system installed in an institutional building: case study in Southern Spain. Renew Sustain Energy Rev 2013;26:147–68 http://dx.doi.org/10.1016/j.rser.2013.05.068. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032113003717⟩.
[27] Travezan JY, Harmsen R, van Toledo G. Policy analysis for energy efficiency in the built environment in Spain. Energy Policy 2013;61:317–26 http://dx.doi.org/10.1016/j.enpol.2013.05.096. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421513004515⟩.
[28] Stead D. Energy efficiency: temporal and geographical trends in Europe. Energy Environ 2009;20(3):345–65.
[29] Torriti J, Hassan MG, Leach M. Demand response experience in Europe: policies, programmes and implementation. Energy 2010;35(4):1575–83 http://dx.doi.org/10.1016/j.energy.2009.05.021. URL ⟨http://www.sciencedirect.com/science/article/pii/S0360544209002060⟩.
[30] Difs K, Bennstam M, Trygg L, Nordenstam L. Energy conservation measures in buildings heated by district heating—a local energy system perspective. Energy 2010;35(8):3194–203 http://dx.doi.org/10.1016/j.energy.2010.04.001. URL ⟨http://www.sciencedirect.com/science/article/pii/S0360544210001921⟩.
[31] Jacobsson S, Bergek A, Finon D, Lauber V, Mitchell C, Toke D, et al. {EU} renewable energy support policy: faith or facts?. Energy Policy 2009;37(6):2143–6 http://dx.doi.org/10.1016/j.enpol.2009.02.043. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421509001347⟩.
[32] Klessmann C, Rathmann M, de Jager D, Gazzo A, Resch G, Busch S, et al. Policy options for reducing the costs of reaching the European renewables target. Renew Energy 2013;57:390–403 http://dx.doi.org/10.1016/j.renene.2013.01.041. URL ⟨http://www.sciencedirect.com/science/article/pii/S0960148113000797⟩.
[33] Resch G, Gephart M, Steinhilber S, Klessmann C, del Rio P, Ragwitz M. Coordination or harmonisation? Feasible pathways for a European RES strategy beyond 2020 Energy Environ 2013;24(1):147–70.
[34] E. Commission, C from the Commission, et al. Energy for the future: renewable sources of energy, white paper for a community strategy and action plan. COM (97) 599 final (26/11/1997); 1997.
[35] Kuiper LC, Sikkema R, Stolp JA. Establishment needs for short rotation forestry in the {EU} to meet the goals of the commission's white paper on renewable energy (November 1997). Biomass Bioenerg 1998;15(6):451–6 http://dx.doi.org/10.1016/S0961-9534(98)00058-0. URL ⟨http://www.sciencedirect.com/science/article/pii/S0961953498000580⟩.
[36] Nilsson M. Red light for green paper: the {EU} policy on energy efficiency. Energy Policy 2007;35(1):540–7 http://dx.doi.org/10.1016/j.enpol.2005.12.023. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421506000024⟩.
[37] Bertoldi P, Huld T. Tradable certificates for renewable electricity and energy savings. Energy Policy 2006;34(2):212–22 http://dx.doi.org/10.1016/j.enpol.2004.08.026. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421504002745⟩.
[38] E. Commission, C. from the Commission, et al. Directive 2009/28/ec of the European parliament and of the council on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/ec and 2003/30/ec. ⟨http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF⟩; 2009 [accessed August 2013].
[39] Plan de acción nacional de energías renovables. ⟨http://www.minetur.gob.es/energia/desarrollo/EnergiaRenovable/Documents/20100630_PANER_Espanaversion_final.pdf⟩; 2010 [accessed August 2013].
[40] EUROSTAT, Energy dependence resources. ⟨http://ec.europa.eu/eurostat/product?code=tsdcc310⟩; 2013 [accessed August 2013].
[41] Montoya FG, Montoya MG, Gómez J, Manzano-Agugliaro F, Alameda-Hernández E. The research on energy in Spain: a scientometric approach. Renew Sustain Energy Rev 2014;29(0):173–83 http://dx.doi.org/10.1016/j.rser.2013.08.094. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032113006345⟩.
[42] Meyer NI. Renewable energy policy in Denmark. Energy Sustain Dev 2004;8(1):25–35 http://dx.doi.org/10.1016/S0973-0826(08)60388-9. URL ⟨http://www.sciencedirect.com/science/article/pii/S0973082608603889⟩.
[43] Fernández PF, Ortiz EV, Bernat JX. The deployment of electricity generation from renewable energies in Germany and Spain: a comparative analysis based on a simple model. Energy Policy 2013;57:552–62 http://dx.doi.org/10.1016/j.enpol.2013.02.027. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421513001122⟩.
[44] Ruiz-Romero S, Colmenar-Santos A, Gil-Ortego R, Molina-Bonilla A. Distributed generation: the definitive boost for renewable energy in Spain. Renew Energy 2013;53:354–64 http://dx.doi.org/10.1016/j.renene.2012.12.010. URL ⟨http://www.sciencedirect.com/science/article/pii/S0960148112007732⟩.
[45] Bampatsou C, Papadopoulos S, Zervas E. Technical efficiency of economic systems of EU-15 countries based on energy consumption. Energy Policy 2013;55:426–34 http://dx.doi.org/10.1016/j.enpol.2012.12.021. URL ⟨http://www.sciencedirect.com/science/article/pii/S030142151201066X⟩.
[46] La energía en españa. http://www.minetur.gob.es/energia/es-es/documents/energia_espana_2011_web.pdf; 2013 [accessed August 2013].
[47] de España RE. The spanish electricity system (2011). English summary. URL ⟨http://www.ree.es/ingles/sistema_electrico/pdf/infosis/sintesis_REE_2011_eng_v2.pdf⟩; 2013 [accessed August 2013].
[48] Martín F, Da Silva-Álvarez RA, Montoro-Pintado P. Effects of wind intermittency on reduction of CO2 emissions: the case of the Spanish power system. Energy 2013;61:108–17, http://dx.doi.org/10.1016/j.energy.2013.01.057.
[49] Pablo-Romero M, Sánchez-Braza A, Pérez M. Incentives to promote solar thermal energy in Spain. Renew Sustain Energy Rev 2013;22:198–208 http://dx.doi.org/10.1016/j.rser.2013.01.034. URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032113000658⟩.
[50] Moreno F, Martíínez-Val JM. Collateral effects of renewable energies deployment in Spain: impact on thermal power plants performance and management. Energy Policy 2011;39(10):6561–74 http://dx.doi.org/10.1016/j.enpol.2011.07.061. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421511005969⟩.
[51] UNESA. Informe eléctrico y memoria de actividades 2011. ⟨http://www.unesa.es/biblioteca/category/10-memorias?download=87:memoria-2011⟩; 2011 [accessed August 2013].
[52] Pereira AJ, Saraiva JT. Long term impact of wind power generation in the Iberian day-ahead electricity market price. Energy 2013;55:1159–71 http://dx.doi.org/10.1016/j.energy.2013.04.018. URL ⟨http://www.sciencedirect.com/science/article/pii/S0360544213003204⟩.
[53] IDAE. Plan de energías renovables (per) 2011–2020. URL ⟨http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_11227_PER_2011-2020_def_93c624ab.pdf⟩; 2011 [accessed August 2013].
[54] de Estadística IN, INE. Horas de sol en españa. URL ⟨http://www.ine.es/jaxi/tabla.do?type=pcaxis&path=/t43/a012/a1998/l0/&file=t200111b.px⟩; 2013 [accessed August 2013].
[55] Atlas radiación españa. URL ⟨http://www.aemet.es/documentos/es/serviciosclimaticos/datosclimatologicos/atlas_radiacion_solar/atlas_de_radiacion_24042012.pdf⟩; 2013 [accessed August 2013].
[56] Şúri M, Huld TA, Dunlop ED, Ossenbrink HA. Potential of solar electricity generation in the European union member states and candidate countries. Solar Energy 2007;81(10):1295–305 http://dx.doi.org/10.1016/j.solener.2006.12.007. URL ⟨http://www.sciencedirect.com/science/article/pii/S0038092X07000229⟩.
[57] Huld T, Müller R, Gambardella A. A new solar radiation database for estimating {PV} performance in Europe and Africa. Solar Energy 2012;86(6):1803–15 http://dx.doi.org/10.1016/j.solener.2012.03.006. URL ⟨http://www.sciencedirect.com/science/article/pii/S0038092X12001119⟩.

[58] Salas V, Olias E. Overview of the photovoltaic technology status and perspective in Spain. Renew Sustain Energy Rev 2009;13(5):1049–57 http://dx.doi.org/10.1016/j.rser.2008.03.011. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032108000506〉.

[59] Prieto P, Prieto P, Hall C. The historical, legal, political, social and economic context of solar photovoltaics in Spain. In: Spain's photovoltaic revolution, Springer briefs in energy. New York: Springer; 2013. p. 21–37. URL http://dx.doi.org/10.1007/978-1-4419-9437-0_3.

[60] Ruiz-Arias J, Terrados J, Pérez-Higueras P, Pozo-Vázquez D, Almonacid G. Assessment of the renewable energies potential for intensive electricity production in the Province of Jaén, Southern Spain. Renew Sustain Energy Rev 2012;16(5):2994–3001 http://dx.doi.org/10.1016/j.rser.2012.02.006. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032112000998〉.

[61] Real decreto 1565/2010. 〈http://www.boe.es/boe/dias/2010/11/23/pdfs/BOE-A-2010-17976.pdf〉; 2010 [accessed August 2013].

[62] Real decreto ley 14/2010. URL 〈http://www.boe.es/boe/dias/2010/12/24/pdfs/BOE-A-2010-19757.pdf〉; 2010 [accessed August 2013].

[63] Zarza E. Concentrating solar thermal power plants and projects in Spain. J Jpn Inst Energy 2010;89(4):302–8 URL 〈http://ci.nii.ac.jp/naid/110008613625/en/〉.

[64] Macroeconomic impact of the solar thermal electricity industry in Spain. URL 〈http://www.protermosolar.com/prensa/2011_10_25/Protermo_Solar_21x21_INGLESC.pdf〉; 2011 [accessed August 2013].

[65] Spanish localization of solar thermal power plants. URL 〈http://www.protermosolar.com/boletines/23/Mapa.pdf〉; 2011 [accessed August 2013].

[66] Araújo KM. National innovations in wind power integration: the cases of Denmark and Spain. In: European wind energy conference & exhibition, vol. 1; 2010. p. 2938.

[67] del Río P, Unruh G. Overcoming the lock-out of renewable energy technologies in Spain: the cases of wind and solar electricity. Renew Sustain Energy Rev 2007;11(7):1498–513 http://dx.doi.org/10.1016/j.rser.2005.12.003. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032106000062〉.

[68] Dincer F. The analysis on wind energy electricity generation status, potential and policies in the world. Renew Sustain Energy Rev 2011;15(9):5135–42 http://dx.doi.org/10.1016/j.rser.2011.07.042. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032111002838〉.

[69] Sahu BK, Hiloidhari M, Baruah D. Global trend in wind power with special focus on the top five wind power producing countries. Renew Sustain Energy Rev 2013;19:348–59 http://dx.doi.org/10.1016/j.rser.2012.11.027. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032112006399〉.

[70] Míguez J, López-González L, Sala J, Porteiro J, Granada E, Morán J, et al. Review of compliance with EU-2010 targets on renewable energy in Galicia (Spain). Renew Sustain Energy Rev 2006;10(3):225–47 http://dx.doi.org/10.1016/j.rser.2004.09.009. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032104001273〉.

[71] Ruiz J, Juárez M, Morales M, Muñoz P, Mendívil M. Biomass gasification for electricity generation: review of current technology barriers. Renew Sustain Energy Rev 2013;18:174–83 http://dx.doi.org/10.1016/j.rser.2012.10.021. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032112005631〉.

[72] Wang L, Weller CL, Jones DD, Hanna MA. Contemporary issues in thermal gasification of biomass and its application to electricity and fuel production. Biomass Bioenerg 2008;32(7):573–81 http://dx.doi.org/10.1016/j.biombioe.2007.12.007. URL 〈http://www.sciencedirect.com/science/article/pii/S0961953407002322〉.

[73] Manzano Agugliaro F. Gasification of greenhouse residues for obtaining electrical energy in the South of Spain: localization by GIS. Interciencia 2007;32(2):131–6.

[74] Font O, Querol X, Plana F, Coca P, Burgos S, Peña FG. Condensing species from flue gas in Puertollano gasification power plant, Spain. Fuel 2006;85(14–15):2229–42 http://dx.doi.org/10.1016/j.fuel.2006.03.029. URL 〈http://www.sciencedirect.com/science/article/pii/S0016236106001116〉.

[75] Ruiz JA, Juarez MC, Morales MP, Lopez-Ochoa LM, Domenech J. Biomass gasification or combustion for generating electricity in Spain: review of its current situation according to the opinion of specialists in the field. J Renew Sustain Energy 2013;5(1):012801 http://dx.doi.org/10.1063/1.4792605. URL 〈http://www.link.aip.org/link/?RSE/5/012801/1〉.

[76] Gómez A, Rodrigues M, Montañés C, Dopazo C, Fueyo N. The potential for electricity generation from crop and forestry residues in Spain. Biomass Bioenerg 2010;34(5):703–19 http://dx.doi.org/10.1016/j.biombioe.2010.01.013. URL 〈http://www.sciencedirect.com/science/article/pii/S0961953410000140〉.

[77] García-Maraver A, Zamorano M, Ramos-Ridao A, Dıaz L. Analysis of olive grove residual biomass potential for electric and thermal energy generation in Andalusia (Spain). Renew Sustain Energy Rev 2012;16(1):745–51 http://dx.doi.org/10.1016/j.rser.2011.08.040. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032111004503〉.

[78] Kasavi C, Finore I, Lama L, Nicolaus B, Oliver SG, Oner ET, et al. Evaluation of industrial *Saccharomyces cerevisiae* strains for ethanol production from biomass. Biomass Bioenerg 2012;45:230–8 http://dx.doi.org/10.1016/j.biombioe.2012.06.013. URL 〈http://www.sciencedirect.com/science/article/pii/S0961953412002498〉.

[79] Canakci M, Topakci M, Akinci I, Ozmerzi A. Energy use pattern of some field crops and vegetable production: case study for Antalya Region, Turkey. Energy Convers Manag 2005;46(4):655–66 http://dx.doi.org/10.1016/j.enconman.2004.04.008. URL 〈http://www.sciencedirect.com/science/article/pii/S0196890404001062〉.

[80] Sauter P, Witt J, Billig E, Thrän D. Impact of the renewable energy sources act in Germany on electricity produced with solid biofuels—lessons learned by monitoring the market development. Biomass Bioenerg 2013;53(0):162–71 http://dx.doi.org/10.1016/j.biombioe.2013.01.014. URL 〈http://www.sciencedirect.com/science/article/pii/S0961953413000299〉.

[81] Alonso-Tristán C, González-Peña D, Díez-Mediavilla M, Rodríguez-Amigo M, García-Calderón T. Small hydropower plants in Spain: a case study. Renew Sustain Energy Rev 2011;15(6):2729–35 http://dx.doi.org/10.1016/j.rser.2011.03.029. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032111001328〉.

[82] de Almeida AT, Moura PS, Marques AS, de Almeida JL. Multi-impact evaluation of new medium and large hydropower plants in Portugal Centre Region. Renew Sustain Energy Rev 2005;9(2):149–67 http://dx.doi.org/10.1016/j.rser.2004.01.015. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032104000450〉.

[83] Estudio del impacto macroeconómico de las energías renovables en españa. URL 〈http://www.appa.es/descargas/APPA_ESTUDIO_2011_WEB.pdf〉; 2011 [accessed August 2013].

[84] Chozas J, Soerensen HC. State of the art of wave energy in Spain. In: Electrical Power Energy Conference (EPEC), 2009 IEEE. http://dx.doi.org/10.1109/EPEC.2009.5420989. URL 〈http://dx.doi.org/10.1109/EPEC.2009.5420989〉; 2009. p. 1–6.

[85] Iglesias G, López M, Carballo R, Castro A, Fraguela J, Frigaard P. Wave energy potential in Galicia (NW Spain). Renew Energy 2009;34(11):2323–33 http://dx.doi.org/10.1016/j.renene.2009.03.030. URL 〈http://www.sciencedirect.com/science/article/pii/S0960148109001517〉.

[86] Iglesias G, Carballo R. Wave energy potential along the death coast (Spain). Energy 2009;34(11):1963–75 http://dx.doi.org/10.1016/j.energy.2009.08.004. URL 〈http://www.sciencedirect.com/science/article/pii/S0360544209003454〉.

[87] Iglesias G, Carballo R. Offshore and inshore wave energy assessment: Asturias (N Spain). Energy 2010;35(5):1964–72 http://dx.doi.org/10.1016/j.energy.2010.01.011. URL 〈http://www.sciencedirect.com/science/article/pii/S0360544210000137〉.

[88] Sierra J, González-Marco D, Sospedra J, Gironella X, Mösso C, Sánchez-Arcilla A. Wave energy resource assessment in Lanzarote (Spain). Renew Energy 2013;55:480–9 http://dx.doi.org/10.1016/j.renene.2013.01.004. URL 〈http://www.sciencedirect.com/science/article/pii/S0960148113000293〉.

[89] Jardón S, Ordóñez A, Álvarez R, Cienfuegos P, Loredo J. Mine water for energy and water supply in the Central Coal Basin of Asturias (Spain). Mine Water Environ 2013;32(2):139–51 http://dx.doi.org/10.1007/s10230-013-0224-x. URL 〈http://dx.doi.org/10.1007/s10230-013-0224-x〉.

[90] Cuchí-Oterino JA, Rodríguez-Caro JB, García de la Noceda-Márquez C. Overview of hydrogeothermics in Spain. Environ Geol 2000;39(5):482–7 http://dx.doi.org/10.1007/s002540050454. URL 〈http://dx.doi.org/10.1007/s002540050454〉.

[91] Lund JW, Freeston DH, Boyd TL. Direct application of geothermal energy: 2005 worldwide review. Geothermics 2005;34(6):691–727.

[92] Antics M, Sanner B. Status of geothermal energy use and resources in Europe. In: Proceedings of the European geothermal congress; 2007. p. 8.

[93] Ley del sector eléctrico 54/1997. URL 〈http://www.boe.es/boe/dias/1997/11/28/pdfs/A35097-35126.pdf〉, 1997.

[94] Real decreto 1955/2000. URL 〈http://www.boe.es/boe/dias/2000/12/27/pdfs/A45988-46040.pdf〉; 2000.

[95] Real decreto 842/2002. URL 〈http://www.boe.es/boe/dias/2002/09/18/pdfs/A33084-33086.pdf〉; 2002.

[96] Real decreto 661/2007. URL 〈https://www.boe.es/boe/dias/2007/05/26/pdfs/A22846-22886.pdf〉; 2007.

[97] Real decreto 1028/2007. URL 〈http://www.boe.es/boe/dias/2007/08/01/pdfs/A33171-33179.pdf〉; 2007.

[98] Real decreto 1578/2008. URL 〈http://www.boe.es/boe/dias/2008/09/27/pdfs/A39117-39125.pdf〉; 2008.

[99] Real decreto-ley 6/2009. URL 〈https://www.boe.es/boe/dias/2009/05/07/pdfs/BOE-A-2009-7581.pdf〉; 2009.

[100] Real decreto 1614/2010. URL 〈http://www.boe.es/boe/dias/2010/12/08/pdfs/BOE-A-2010-18915.pdf〉; 2010.

[101] Real decreto-ley 14/2010. URL 〈https://www.boe.es/boe/dias/2010/12/24/pdfs/BOE-A-2010-19757.pdf〉; 2010.

[102] Ley 2/2011. URL 〈http://www.boe.es/boe/dias/2011/03/05/pdfs/BOE-A-2011-4117.pdf〉; 2011.

[103] Real decreto-ley 1/2012. URL 〈http://www.boe.es/boe/dias/2012/01/28/pdfs/BOE-A-2012-1310.pdf〉; 2012.

[104] Real decreto-ley 9/2013. URL 〈http://www.boe.es/boe/dias/2013/07/13/pdfs/BOE-A-2013-7705.pdf〉; 2013.

[105] Callejon-Ferre AJ, Manzano-Agugliaro F, Diaz-Perez M, Carreno-Sanchez J. Improving the climate safety of workers in Almería-type greenhouses in Spain by predicting the periods when they are most likely to suffer thermal stress. Appl Ergon 2011;42(2):391–6 http://dx.doi.org/10.1016/j.apergo.2010.08.014. URL 〈http://www.sciencedirect.com/science/article/pii/S0003687010001286〉.

[106] Márquez AL, Baños R, Gil C, Montoya MG, Manzano-Agugliaro F, Montoya FG. Multi-objective crop planning using pareto-based evolutionary algorithms. Agric Econ 2011;42(6):649–56 http://dx.doi.org/10.1111/j.1574-0862.2011.00546.x. URL 〈http://dx.doi.org/10.1111/j.1574-0862.2011.00546.x〉.

[107] Fernández-García A, Zarza E, Valenzuela L, Pérez M. Parabolic-trough solar collectors and their applications. Renew Sustain Energy Rev 2010;14(7):1695–721 http://dx.doi.org/10.1016/j.rser.2010.03.012. URL 〈http://www.sciencedirect.com/science/article/pii/S1364032110000675〉.

[108] Rosiek S, Garrido FJB. Performance evaluation of solar-assisted air-conditioning system with chilled water storage (CIESOL building). Energy Convers Manag 2012;55:81–92 http://dx.doi.org/10.1016/j.enconman.2011.10.025. URL 〈http://www.sciencedirect.com/science/article/pii/S0196890411003062〉.

[109] Iglesias G, del Río P, Ángel Dopico J. Policy analysis of authorisation procedures for wind energy deployment in Spain. Energy Policy 2011;39(7):4067–76 http://dx.doi.org/10.1016/j.enpol.2011.03.033. URL ⟨http://www.sciencedirect.com/science/article/pii/S0301421511002138⟩.
[110] Hernandez-Escobedo Q, Manzano-Agugliaro F, Zapata-Sierra A. Wind strength description in the Province of Almeria. DYNA 2009;84(8):681–6.
[111] Todt O, González MI, Estévez B. Conflict in the Sea of Trafalgar: offshore wind energy and its context. Wind Energy 2011;14(5):699–706 http://dx.doi.org/10.1002/we.446. URL ⟨http://dx.doi.org/10.1002/we.446⟩.
[112] Feria MJ, Rivera A, Ruiz F, Grandal E, García Domínguez JC, Pérez A, et al. Energetic characterization of lignocellulosic biomass from Southwest Spain. Int J Green Energy 2011;8(6):631–42 http://dx.doi.org/10.1080/15435075.2011.600378. URL ⟨http://www.tandfonline.com/doi/abs/10.1080/15435075.2011.600378⟩.